



IRON: ITS SOURCES, PROPERTIES,
AND MANUFACTURE

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IRON

ITS SOURCES, PROPERTIES,
AND MANUFACTURE

WITH NUMEROUS ENGRAVINGS AND DIAGRAMS

BY

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GENERAL

PREFACE.

IRON : ITS SOURCES, PROPERTIES, AND MANUFACTURE contains, in a form convenient for everyday use, a comprehensive treatise on the subject. The contents of this manual are based on the highly esteemed book written by the late William Henry Greenwood.

Without omitting any essential part of the original work the matter has been revised, partly rewritten, and brought up to date by Mr. A. Humboldt Sexton, F.I.C., F.C.S., Professor of Metallurgy in the Glasgow Technical College. Needless to say, many changes have taken place since the previous edition was published, and whilst descriptions of new processes and appliances have been given, those of the older methods which are still in vogue in many works have been retained and revised. In this manner the manual has been made valuable, not only to the student but to all employed in iron works.

Readers who may desire additional information respecting special details of the matters dealt with in this book, or instructions on any kindred subjects, should address a question to the Editor of *WORK, La Belle Sauvage, E.C.*, so that it may be answered in the columns of that journal.

P. N. HASLUCK.

*La Belle Sauvage, London,
July, 1907.*

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IRON: ITS SOURCES, PROPERTIES, AND MANUFACTURE.

CHAPTER I.

INTRODUCTION ; TERMS EXPLAINED.

IRON in a chemically pure state exists only as a curiosity, and has no practical application in the arts. It has no value as a constructive material, and cannot be prepared upon a large scale. Iron in combination with small proportions of carbon and other elementary bodies, as sulphur, silicon, phosphorus, etc., yields the various commercial forms of iron which are known as steel, malleable- or wrought-iron, and cast- or pig-iron, and these metals are by far the most important known.

The forms in which iron comes into the market are so many and so varied that it is very difficult to draw up satisfactory definitions. In general, the metal is called either iron or steel, the classification depending partly on chemical composition and partly on method of manufacture.

In this manual it is intended to deal with the varieties commercially known as iron, leaving the consideration of steel to a companion manual. The forms known as iron have been much longer in use than those known as steel, and are much more easy to define accurately—accurately, that is, from a technical rather than from a purely scientific standpoint.

There are two familiar forms of iron, very different in their character.

(1) **Malleable- or Wrought-Iron.**—This is undoubtedly the form in which iron was first used in the arts. It is still largely used, but is being gradually displaced for most purposes by mild steel, which, in many of its forms, it very closely resembles. It is comparatively pure, containing about

99·5 per cent. or thereabouts of pure iron, a small quantity of carbon up to ·2 per cent. or thereabouts, a small quantity of silicon—say ·1 per cent., and small quantities of other impurities. It is very malleable and ductile—that is, it can be rolled into sheet, or drawn into wire, either hot or cold—and when heated to bright redness it becomes so soft that it can be hammered or wrought into any required form, whence its common name. It is usually regarded as being the purest form of iron in commerce, but mild steels are now made of a higher degree of purity. It cannot be melted in an ordinary fire fed with solid fuel, and articles of it are always prepared by hammering, rolling, stamping, spinning, or similar processes, portions being united either by welding at a red heat or by a mechanical connection such as riveting.

(2) **Cast-iron or Pig-iron.**—This is the most impure form of iron, containing large quantities of various foreign constituents, some of which, however, can hardly be called impurities, since the metal would not be cast-iron if they were absent. The amount of iron present varies considerably, but usually is about 92 to 93 per cent. Carbon is always present, usually about 3·5 per cent., though it may reach 4·5, and silicon may range from about ·5 per cent. (in rare cases) up to 3·5 per cent. or even higher. Cast-iron may, indeed, be defined as being iron containing over 2 per cent. of carbon and some silicon, these being the essential constituents; whilst the other elements—sulphur, phosphorus, manganese, etc.—though almost always present may be regarded as being accidental constituents or impurities, because the absence of them would not prevent the metal being cast-iron. Cast-iron is prepared in a liquid condition, and as it flows from the furnace is usually cast into pigs, and is therefore called pig-iron. It is converted into the forms which may be required by melting and casting in moulds, of sand or other material, and therefore it is often called cast-iron.

Either one of these two forms of iron may be prepared directly from the ore or one from the other. In the very early days malleable iron was prepared directly, and cast-iron was unknown, but now cast-iron is always prepared directly from the ore, and malleable-iron is prepared from cast. In this manual, therefore, the preparation of cast- or pig-iron will be first described and explained.

Scope of this Manual.—Such metals as iron and steel may be studied from so many standpoints that it may be as well to indicate briefly the scope of this manual. It is intended to deal with the metals from the metallurgical standpoint only. That is, to describe the sources of the metals in nature and the methods by which the metal is obtained from these sources and prepared for subsequent use. Chemical subjects will have to be considered, but they will be dealt with only so far as they bear on the metallurgy of the metals. The properties of the metals will, of course, be discussed; but these will be considered mainly from the standpoint of the influence of impurities, of methods of manufacture and of treatment of the metal, not so much from the engineer's standpoint, as the use for which the metal is intended.

Technical Terms.—It is impossible to write a technical book without the use of technical terms, and brief explanations of a few of the terms that will be used are given below. These are only intended as a guide to the student who is quite new to the subject, and most of them will be discussed more fully in the text as occasion arises.

Annealing, in the case of iron and steel, is the term applied to the operation by which the metal is heated to bright redness, and then allowed to cool down slowly, either in the open air, or, more usually, under a layer of ashes or other bad conductor of heat. Annealing often corrects or prevents the irregularities in strength arising from unequal or irregular cooling in castings and forgings, and removes the hardening effect of work. The term annealing is also used for the long heating which is given to castings in the preparation of malleable cast-iron, and also to the operation of slowly heating crucibles to redness before introducing them into the steel melting furnace.

Calcination is the process in which iron-ores are heated in heaps, or kilns, at a comparatively low temperature, for the expulsion of water, carbon dioxide (CO_2), sulphur, and other volatile matters, with the oxidation of the ferrous oxide and carbonate to the condition of ferric oxide. The necessary heat is produced either by the combustion of the bituminous matters in the ore itself, as in certain Scotch blackband ironstones, by the combustion of sulphur in highly

sulphurous ores of copper and other metals, or by the addition of fuel which is mixed with the ore to be calcined in the heaps or kilns.

Cementation is a process in which a metal is made to take up a solid element, by being heated with it. In the metallurgy of iron the principal example is the carburising of malleable-iron, and the production of steel, by the prolonged exposure of the iron at a temperature below fusion, to the action of solid carbon. A similar action may go on in the blast furnace where the freshly reduced iron is in contact with the carbon of the fuel.

Cold-short expresses a condition of iron or other metal in which when it is worked by hammering or rolling at or below a dull red-heat the edges crack or fracture according to the degree of the cold-shortness; perhaps such metal may be worked with the utmost facility at a higher temperature. Small quantities of phosphorus, silicon, arsenic, and antimony induce cold-shortness in iron or steel, phosphorus being the most common cause of this defect.

Red-short is a term applied to metals which cannot be readily worked at a temperature at or above redness, although frequently such metal can be worked by hammering or rolling at ordinary temperature without fracture. Red-shortness is often the result of the presence of an undue proportion of sulphur in the metal, but copper, antimony, silver, calcium, etc., also produce the same effect.

Malleability is the quality of permanently extending in all directions, without rupture, by pressure, as by hammering or rolling, and is an essential quality of metal that is to be rolled into sheets. Russian sheet-iron has been reduced to a thickness not exceeding 770 to the inch.

Ductility is the property of being permanently extended by a tensile force, or drawn into wire. It depends partly on the malleability and partly on the tenacity of the metal. All malleable metals are more or less ductile. It is greatly influenced by the presence of impurities in the metals, and also varies with the temperature.

Elasticity.—When a substance is subjected to stress, it undergoes a change in form and perhaps in size also. For example, a bar subjected to a pulling stress will become longer. It is obvious that the force with which the bar

resists extension is the same as the force which is applied to produce the extension, and this is the measure of the elasticity of the body. The greater the force with which the body tends to return to its original form—that is, the greater the force needed to produce the extension—the greater is the elasticity of the substance.

If a bar of iron of 1 sq. in. in section be taken and a force of 1 ton be applied the bar will be stretched by a definite fraction of its own length. If the force be doubled the extension will be doubled, and so on, the extension being proportional to the extending force, or, as it is usually put, the strain is proportional to the stress. The modulus of elasticity, or Young's modulus, is the force that would be required to double the length of the bar provided the law of proportionality of stress and strain held good and the bar did not break. This condition can never be attained, but the modulus can be calculated from the ratio of strain to stress at lower pressures. The modulus of elasticity is the recognised measure of the elasticity of a substance.

If to the bar, of say 1 sq. in. in section, a stress of 1 ton be applied, the bar will elongate; if 2 tons, it will elongate by double the amount, and so on as already explained. Also, if the stress of 1 ton be removed, the bar will return to its original length, so also if the 2 tons be removed, and so on; but as the stretching force is increased a point is reached when the stretching ceases to be proportional to the force applied, and when, if the stretching force is removed, the bar does not return exactly to its original length, but has taken a permanent set. This is the limit of elasticity. The two factors, the Modulus of Elasticity and the Limit of Elasticity, are of the utmost importance in determining the utility of metals for structural purposes.

In the preceding paragraphs the elasticity has been considered only in the case of a stress in tension tending to lengthen the bar, but exactly the same laws hold good in the case of stresses producing compression or any other form of distortion.

Tenacity is the property of resisting fracture from the application of a tensile or stretching force, and is usually stated in England in terms of the number of tons or hundred-weights required to break a bar of 1 sq. in. sectional area.

Figs. 1 to 6 show the common forms of test pieces. Figs. 7 to 11 show the forms of standard tensile test pieces as proscribed by the Engineering Standards Committee.

In France, Germany, and generally over the Continent, the force or weight is expressed in kilogrammes (2·2046 lb.) with the square centimetre as the unit of area (the square centimetre = 0·15500591 sq. in.). Tons per sq. in. \times 0·00635 =



Fig. 1.—Cylindrical Test Piece with Screwed Ends.



Fig. 2.—Fractured Test Piece with Screwed Ends.

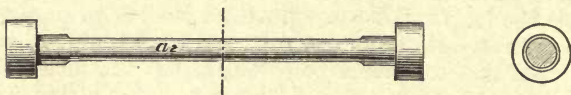


Fig. 3.—Cylindrical Test Piece with Button Ends.



Fig. 4.—Fractured Test Piece with Button Ends.



Fig. 5.—Bar Test Piece.



Fig. 6.—Fractured Bar Test Piece.

kilogrammes per square centimetre (kg. per cm.). The tensile strength of a metal depends on its composition and also on the treatment to which it has been subjected. It is easily measured, and therefore is taken as one of the standards in the specification of metals.

Extension.—When a bar is subjected to tensile stress it extends very considerably before fracture, so that the piece when the broken edges are put together, is longer than the

original piece. The increase in length is the extension or elongation. As it does not take place equally over the whole length of the test piece, the length of the test piece used must

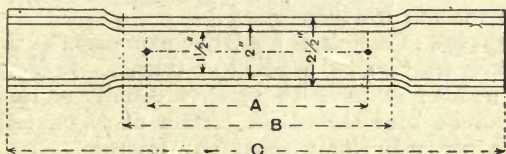


Fig. 7.—Test Piece for Plates (Standard Form): A, gauge, length 8 in.; B, parallel for not less than 9 in.; C, total length above 18 in.

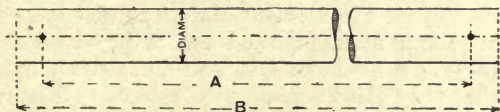


Fig. 8.—Test Piece for Bars, etc. (Standard Form): A, parallel for not less than 8 times the diameter; B, enlarged ends parallel for not less than 9 times the diameter.

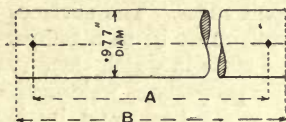
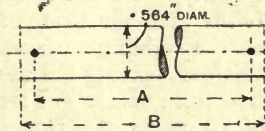
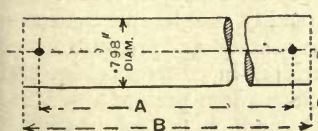


Fig. 9.—Test Piece for Forgings, Castings, etc. (Standard Form): A, gauge, length $3\frac{1}{2}$ in.; B, parallel for not less than 4 in.



Figs. 10 and 11.—Test Pieces for Tyres, Axles, Forgings, Castings, etc.

always be stated. It is usually 8 in. or 10 in. for testing iron or steel.

Fatigue is the diminished resistance to fracture which comes after repeated applications of stress, especially after stresses varying within a wide range.

Fining is an old term, still used in some districts, and usually describes a process of purification by oxidation.

Softness is a relative term sometimes used to express the quality of a metal whereby it easily permanently yields to pressure without fracture.

Toughness, in metals, is a relative expression of the power of resisting fracture by bending or torsion. It is measured by the number of times to which a definite section of the metal can be bent through a certain angle on either side from the perpendicular without any fracture.

Flow of Metals.—When metals are subjected to great stress they pass into a condition in which the molecules can flow freely one over the other, and therefore in which the metal behaves for the moment almost as if it were a liquid. All metal rolling, stamping, and similar processes depend on this property. Some metals, as lead and some alloys, flow so readily that they can be made into tubes or other forms by extrusion through dies. Malleability and ductility are due to this flow of the metal.

Welding is the quality whereby two clean surfaces, brought together at a suitable temperature, under pressure will unite to form one coherent mass. The surfaces must be perfectly clean, and the metals must be at a temperature high enough to produce a plastic state in which there is considerable molecular freedom. This property of welding is typically shown by wrought-iron at a white heat, and by the milder qualities of steel at a red or white heat. It is essential that the surfaces be free from oxide, and to obtain this with iron a quantity of sand (silica) is thrown on the surfaces; this forms with the oxide of iron a readily fusible and fluid slag on the welding surface, and the subsequent pressure forces this out, leaving the metallic surfaces in contact, clean and free from oxide. For steel the smith often prefers a mixture of 10 parts of borax ($\text{Na}_2\text{B}_4\text{O}_7$) and 1 of sal-ammoniac (NH_4Cl) to 1 of sand. In order that two metals should weld well it is essential that the point of maximum-molecular freedom in each should be at about the same temperature.

Ore is the metalliferous material extracted from the mine, and to be considered as an ore it must contain enough of the metal to pay for extraction. The ores of iron are

oxides or carbonates of the metal, accompanied by certain extraneous matters, gangue, or vein stuff, essentially siliceous, calcareous, argillaceous, or bituminous in character. In Wales and some other districts the term "mine" is used as synonymous with ore.

Smelting is the separation or extraction of a metal from its ores on a large scale. When the ore is an oxide the process is one of reduction. The active element used in effecting the reduction is known as the "reducing agent," and in the case of iron this is invariably carbon or carbon-monoxide (CO), always at a high temperature.

Flux is a substance added to the furnace charge, which, by combining with the siliceous and other extraneous matters or gangue of the ore, yields at the furnace temperature a readily fusible substance known as a slag. Iron ores having a gangue of infusible quartz might be smelted without the addition of flux, but this would cause a loss of iron, since ferrous oxide (FeO) readily combines with quartz or silica, producing a fusible ferrous silicate, which is not reducible by carbon or carbonic oxide, the reducing agents of the blast furnace, and which therefore would pass away into the slag with a corresponding loss of iron. A similar result follows if the gangue be argillaceous, for the aluminous silicate (clay), which alone is practically infusible, combines readily with a portion of the ferrous oxide of the ore, producing thereby a double silicate of alumina and iron, which is easily fusible; but to obviate the loss of iron which would thus result it is usual to add a flux of limestone, the lime of which enters into combination with the silica or siliceous clay, yielding fusible silicates, or slags of the double silicates of lime and alumina. When the ores are the rich oxides of iron (hæmatites), lime and also argillaceous matters, in the form of shales or argillaceous iron-ore, are often added.

Slags are the earthy portion of the ores combined, when necessary, with fluxes so as to produce a fusible mass which can be tapped from the furnace in a liquid condition.

A slag must be fusible at the temperature of the furnace, so that it can be tapped out, and must be of sufficiently low specific gravity, and sufficiently liquid, to allow the metal to separate readily, and it should be as free as possible from the metal being smelted. Slags are almost invariably silicates:

in iron smelting, silicates of lime and alumina ; and in lead and copper smelting, and in the preparation of malleable iron by puddling, silicates of iron.

Slags always form an important part of the by-products of any metallurgical industry, and the profitable disposal of them is an important part of the economies of the works. The character of slags produced in the various branches of the iron industry, and the use that can be made of them, will be discussed later.

Puddling is a process by which pig-iron or refined iron is converted into malleable iron in fixed reverberatory furnaces. The term pig-boiling is sometimes applied to the process of puddling as now carried out.

Refining is the process sometimes employed to effect the partial purification of pig-iron by the removal of silicon, so converting it into white, refined, or plate metal. This is a preliminary to its conversion into malleable iron by treatment in the puddling furnace or charcoal finery.

Shingling, or nobbling, is the treatment received by the puddled ball under the hammer, for the welding together of its particles into a solid bloom, and the expulsion of slag and oxides from the puddled ball.

Temperatures employed in working iron and steel are often expressed by such terms as "red-heat," "white-heat," etc., and the following figures indicate approximately the temperatures so defined :—

Incipient redness	about	525° C. (977° F.).
Dull red	"	700° C. (1292° F.).
Cherry red	"	900° C. (1652° F.).
Deep orange	"	1100° C. (2012° F.).
White-heat	"	1300° C. (2372° F.).
Dazzling white	"	1500° C. (2732° F.).
		to 1600° C. (2912° F.).

CHAPTER II.

REFRACTORY MATERIALS, CRUCIBLES, ETC.

REFRACTORY materials are used in the metallurgical treatment of iron and steel for the building and lining of furnaces, for the preparation of crucibles, and other minor purposes. Those most used are fire-clays, refractory sands, fire stones (refractory rocks), lime, magnesian lime, graphite, etc. The most generally used material is clay, which is the basis of nearly all the firebricks used, and of all the crucibles.

Clay is essentially a hydrated silicate of alumina, the purest form, Kaolin, having the formula $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$. The most important property of clay is its plasticity. That is, when mixed with water, in addition to that which it contains in combination, the mass becomes so plastic that it can be moulded to any required form. On drying, the mass acquires some firmness, and on heating to redness the water of combination is expelled, the mass becomes hard, and is no longer capable of being made plastic by the addition of water. The combined water has been expelled.

All natural clays contain other materials intermixed with the clay, and when these are of such a character as not to seriously impair its power of resisting a high temperature it is called a fire-clay.

Pure kaolin contains 46.4 per cent. of silica ; it is very infusible, but cannot be used for making fire-bricks. The fire-clays tabulated on the next page—and it is true also of almost all others—contain a large excess of silica over and above that present in the clay.

The value of a fire-clay largely depends upon its freedom from such bodies as lime, magnesia, ferrous oxide, and particularly the alkalis, any of which at high temperatures would readily combine with the free silica (SiO_2) of the clay, with the formation of readily fusible silicates. The presence of 3 to 4 per cent. of foreign basic oxides in

an ordinary clay—that is, one that contains much free silica—will render it fusible; but the more aluminous the clay the larger is the allowable quantity of bases.

The following analyses of well-known fire-clays will give an idea of their composition :—

ANALYSES OF FIRE-CLAYS.

	A	B	C	D
Silica	63·30	67·12	66·10	44·37
Alumina	23·30	21·18	19·80	38·59
Potash	—	2·02	—	—
Soda	—	—	—	—
Lime	·73	·32	—	·51
Magnesia	—	·84	—	·30
Ferrous Oxide (FeO) . .	1·80	—	—	1·82
Ferric Oxide (Fe ₂ O ₃) . .	—	1·85	6·30	—
Water Combined . . .	—	4·82	—	—
„ Hygroscopic . . .	10·30	1·39	7·50	14·47
Organic Matter . . .	—	·90	—	—
	99·43	100·44	99·70	100·00

A.—Stourbridge Clay. B.—South Wales Clay. C.—Continental Clay used for Fire-bricks. D.—Garnkirk Clay.

Ferric oxide, if present in large quantity, imparts a reddish colour to the burnt clay. It does not much reduce the refractoriness of the clay, provided it is only used in an oxidising atmosphere, as ferric oxide and silica do not combine; but heated in a reducing atmosphere, it is reduced to ferrous oxide, which readily combines with silica. Iron pyrites is usually present in tiny particles distributed through the mass of clay. During firing the sulphur is burnt out and ferrous oxide is formed. This combines with the silica, forming black ferrous silicate, which sinks into the porous clay, and a tiny hole is left where the pyrites was, surrounded by a black stain of ferrous silicate.

Fire-clays occur largely in the coal measures of the carboniferous strata, also in various other geological formations. Most of those used in the manufacture of fire-bricks belong to the carboniferous period. Clays obtained from the same locality and apparently of the same kind are found to differ widely in their degree of fusibility, this to a large extent arising from variations in the proportions of silica.

If a material will readily combine with a basic oxide at a high temperature it is said to be an acid material, silica being the acid substance almost invariably present; on the other hand, if it will combine readily with siliceous materials it is said to be basic, whilst if it can be heated either with silica or with a basic oxide without fusion it is said to be neutral. The large quantity of silica in all ordinary fire-clays shows them to be distinctly acid bodies, in the sense defined above. Much more acid materials are often used.

Ganister is a siliceous rock containing just enough clay to bind the mass together. Dinas rock or Dinas clay is a siliceous rock of no binding power, containing often as much as 98 per cent. of silica, and even more siliceous materials are sometimes used, as, for instance, calcined flints, which are used in the manufacture of some silica bricks, and fine white sand, which is nearly pure silica.

Rocks, etc.—Fire stones, very refractory sandstones, are sometimes used in furnace construction. They are hard and difficult to work, and therefore costly; but they yield the most durable bottoms for the blast furnace, and therefore are still largely used for that purpose. Rocks can never be used in places subject to sudden fluctuations in temperature.

Fire-bricks.—Clay is almost invariably made into fire-bricks; these should withstand continued exposure to the highest temperatures of a furnace without decomposition, cracking, fusing, or sensibly softening; they should bear considerable pressure whilst heated without suffering fracture or distortion; they should be unaffected by considerable, and sometimes sudden, variations of temperature. For certain purposes they require to be unaffected by contact at a white heat with such metallic oxides as those of iron and magnesia, or other basic slags or scorïæ; contact with heated fuel should be without effect upon them; they should be able to resist at one time an oxidising, and at another a reducing, action. For convenience in building fire-bricks are required to be regular in shape and uniform in quality.

All these qualities are never to be found to perfection in one brick; and in each case the best possible compromise has to be made. For blast-furnace construction, bricks such as the Glenboig, which have not a very large excess of silica present, are the most suitable, and highly siliceous bricks are

to be avoided, as the slags contain a considerable quantity of lime. In the upper part of the blast furnace, where the temperature is not very high, highly refractory bricks are not by any means necessary.

In the manufacture of fire-bricks, their constituent fire-clays cannot be used directly as they are found—that is, in the raw state—since, although the clay may be sufficiently refractory for the purpose intended, yet it is not sufficiently uniform in composition, and if used alone the brick would shrink far too much.

The clay is sometimes tempered by exposure to the air, protected from rain, for some time, and is then crushed in a suitable mill to a coarse powder. Any necessary addition to prevent shrinkage is then made. The usual substance added is burnt clay in the form of old bricks, but cinders, graphite, sand, or other materials may be used. Whatever the material is, it is crushed to the same degree of fineness as the clay, and the materials are then mixed with water and thoroughly incorporated in a pug-mill; and moulded into bricks by machine or hand labour, as in the case of ordinary bricks. The bricks are then laid out to dry, and, when sufficiently dry and resisting, are placed in kilns, each holding from 15,000 to 20,000, arranged so as to allow of the heated gases from the combustion of the fuel burning on a grate at the end of the kiln to circulate around and between them. After some six days' exposure to heat in this manner, the bricks are sufficiently burnt and ready for withdrawal, for which purpose the fires are drawn, and the kilns allowed to cool down. Gas fired kilns are now largely used for brick burning. The shrinkage during the drying and burning of fire-bricks is considerable, so that for the production of a 9-in. brick the raw clay brick will require to be from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. longer than the burnt brick; the exact amount requires to be determined for each mixture of clay, since the amount of contraction varies for almost every clay or mixture of clays.

Fire-bricks must be set in fire-clay and never in lime mortar, otherwise at furnace temperatures the free silica of the brick will combine with the lime of the mortar, and produce a readily fusible silicate of lime, with consequent destruction of the furnace.

Silica bricks are made much in the same way, but the

crushed siliceous material is mixed with a small quantity (about 1 per cent.) of lime, which combines with some of the silica and forms a silicate which frits the whole together. Such bricks are never strong.

ANALYSES OF FIRE-BRICKS, SILICA BRICKS, GANISTER.

	A	B	C	D	E
Silica . .	62·10	58·00	97·5	92·0	96·7
Alumina . .	33·10	36·50	1·4	5·0	1·3
Ferric Oxide . .	3·00	1·67	0·55	2·5	
Lime . .	0·90	0·50	0·15	0·3	2·0
Magnesia . .	trace	0·90	0·10	0·2	—
Potash . .	0·90	2·12	—	—	—
Soda . .	—	0·30	—	—	—
	100·00	99·99	99·70	100·0	100·0

A.—Glenboig Fire-brick. B.—Newcastle Fire-brick. C.—Dowlais Silica Brick. D.—Sheffield Ganister Brick. E.—Silica Brick.

Siliceous sand is an exceedingly refractory material, containing in some varieties as much as 97 per cent. of silica, the remainder consisting of a little lime, alumina, oxides of iron and water. This sand is used for mixing with fire-clays, etc., in the manufacture of fire-bricks, also as the principal ingredient in the mortar used in the setting of silica bricks; it is also employed in making the bottom or hearth of the Siemens melting furnace. Sands less pure than the above, containing enough clay to give binding power, are also employed for making the pig-beds of blast furnaces, and more plastic sands for making moulds for casting iron.

Such material as silica, dinas-rock, ganister, and ordinary fire-clays contain excess of silica and are acid in character, that is, they tend to combine with bases and form fusible silicates. For some purposes this is objectionable, and basic materials must be used. Of these but four are available: bauxite, lime, magnesia, and the mixture of the two—magnesia lime—obtained by burning magnesian limestone.

Lime occurs in Nature as carbonate in limestones. Magnesian limestone occurs in the north of England, and magnesite (magnesium carbonate) occurs in a few localities. When any of these are heated, carbon-dioxide is expelled, and lime,

magnesian lime, or magnesia, as the case may be, is left. These substances are all basic, but they have no binding power, and lime absorbs moisture and carbon-dioxide so rapidly from the air that a brick or lining made from it would soon fall to pieces. The same action takes place with magnesia or magnesian lime, but to a less extent. The magnesian limestone of the north of England contains about 3 to 5 per cent. of silica, which at a high temperature frits the whole together. In the manufacture of basic bricks hot anhydrous tar is used to hold the material together until this temperature is reached. Basic materials are chiefly used for lining furnaces or converters for the basic steel processes.

The neutral materials used in furnace combustion are graphite or blacklead, and chromite, or chrome iron ore, C_2O_3FeO . These are almost exclusively used in the steel furnace, and therefore do not need more than a mention here.

CHAPTER III.

ORES OF IRON:

IRON is present in a vast number of minerals, though its workable ores are not very numerous, and do not differ as widely in their chemical composition and richness as the ores of some other metals. The only minerals worked for the production of iron are either the oxides or the carbonates of iron, accompanied by a gangue, or foreign matters, usually consisting largely of calcareous, siliceous, argillaceous, or bituminous minerals; and it is upon the nature and quantity of the foreign matter present that the desirability of working the deposit of ore depends. Thus a hæmatite iron ore, though rich in iron, would be of little value, perhaps of no value, if it contained a considerable proportion of a mineral phosphate (as calcium phosphate) or ferrous sulphide (iron pyrites); whilst 5, 10, or 15 per cent. of manganese in spathic ores, or of carbonaceous matters in a clay ironstone, would enhance the value of the ore.

The sulphides and silicates of iron occur very abundantly as minerals and metallurgical products, but for reasons to be subsequently explained are not available as ores of iron. Of the oxides of iron used in iron-smelting, the most important are the magnetites, and the red and brown hæmatites, whilst the carbonates include the spathic iron-ores, the argillaceous carbonates known as clay ironstones, and the black band ironstone.

Iron ores occur in almost the whole of the geological series, but most abundantly in the older formations, as the Silurian, Devonian, and Carboniferous, although the brown and argillaceous hæmatites and the carbonates also occur rather largely in the Oolites of Europe.

Native iron, in the form of hard fine-grained buttons known as "native steel," is sometimes found where coal seams have

been ignited in the vicinity of ferruginous deposits; and "meteoric iron" is found in large or small masses which have fallen upon the earth from space outside; but these are of such comparatively rare occurrence, irregular distribution, and small weight, as not to be considered amongst the ores or sources of iron, as employed in the arts.

Magnetite or magnetic iron-ore is the richest and one of the most widely distributed of the ores of iron. The pure mineral is iron-black or iron-grey in colour, it gives a black streak, is brittle, magnetic, and sometimes distinctly polar; it occurs crystallised in the cubic system as octahedra and dodecahedra, but is more generally found in the massive form, yielding a crystalline or granular fracture; and it is also found in the form of grains or sand. The composition of magnetite is represented by the formula Fe_3O_4 , or Fe_2O_3 , FeO ; when pure it yields 72.41 per cent. of iron, but the two oxides FeO , Fe_2O_3 , are rarely present in any simple atomic proportion, and the ore usually contains only from 80 to 90 per cent. of the magnetic oxide of iron, accompanied with from 5 to 15 per cent. of silica. The Swedish magnetites imported into England are practically free from sulphur and phosphorus, and some contain considerable proportions of manganese. Magnetites occur which contain considerable quantities of both sulphur and phosphorus. These, however, are only exported after magnetic concentration.

Magnetic iron ore occurs in granite, gneiss, clay-slate, hornblende-schist, and other metamorphic rocks, and it is also often accompanied by red and brown hæmatites. It is from these ores (magnetites) smelted with charcoal that the famed Dannemora (Swedish) iron is obtained. The ore employed at Dannemora yields from 25 to 60 per cent. of metallic iron, but the average falls below 50 per cent.; the ore is accompanied by a gangue, containing silica and lime, in sufficient quantities to permit of its being smelted without the addition of any further flux to the furnace charge. Magnetic iron ore is found in considerable abundance in Norway and Sweden, whence it is exported in large quantities; it occurs also in Piedmont, Saxony, Canada, the United States, Mexico, the Urals, Siberia, the Island of Elba, in the West of England, in Devon, and in Cornwall, but the British deposits are not worked.

ANALYSES OF MAGNETIC IRON-ORE.

	A	B	C	D	E	F
Ferric oxide (Fe_2O_3)	27.50	68.98	13.00	72.17	68.8	67.31
Ferrous oxide (FeO)	56.80	—	66.50	2.20	21.7	28.33
Manganous oxide (MnO)	0.24	0.37	0.56	.27	0.16	trace
Alumina (Al_2O_3)	—	3.81	3.60	.35	—	—
Lime (CaO)	1.80	1.21	0.56	3.42	—	—
Magnesia (MgO)	.80	—	1.52	8.53	—	—
Silica (SiO_2)	13.20	24.76	—	10.51	—	—
Phosphoric anhy- dride (P_2O_5)	—	0.03	0.57	.024	P. .008	0.07
Ferrous sulphide (FeS_2)	—	—	0.04	.029	—	0.09
Water (OH_2)	—	—	3.20	1.93	—	TiO_2 .11
Insoluble residue	—	—	9.40	—	—	3.97
	100.34	99.16	98.95	99.433	—	99.88
Metallic iron per cent.	61.16	—	56.66	53.97	63.84	—

A.—Dannemora ore (Ward). B.—Oural ore. C.—Devonshire (Riley). D.—Persberg. E.—Bispsberg (Akerman). F.—British Columbia.

Franklinite is less magnetic than magnetite, which it otherwise closely resembles; it occurs in the metamorphic Silurian limestones of New Jersey, United States. In New Jersey it is first treated for the extraction of zinc, and the residues so obtained are afterwards smelted for spiegeleisen. Franklinite is a mixture of ferric and manganic oxides $(\text{Fe, Mn})_3\text{O}_4$ with ferrous, manganous and zinc oxide $(\text{Fe, Mn, Zn})\text{O}$, of which Rammelsberg gives as the average of several analyses 45.16 per cent. of iron, 9.38 per cent. of manganese, 20.3 per cent. of zinc, with 25.16 per cent. of oxygen, but the composition is very variable. It is usually regarded as magnetite in which the ferrous oxide (FeO) is replaced by zinc oxide (ZnO).

Chrome Ores.—Chrome iron ore (chromite) may be regarded as being magnetite in which a large proportion of the ferric oxide is replaced by chromic oxide ($\text{Cr}_2\text{O}_3\text{FeO}$). These ores have long been used as the source of chromic acid and the chrome salts of commerce. They are also valuable as a neutral material for furnace linings, and since the introduction of chrome steels they have been

smelted for the preparation of chrome iron—an alloy of iron and chromium. Chromite is black in colour, and very closely resembles magnetite in properties; the streak is browner, and it is less—sometimes not at all—magnetic. It, of course, gives the blowpipe reactions for chromium. Chrome ores are largely imported from Eubœa in the Greek Archipelago, Turkey, New Caledonia, and other localities.

Manganese Ores.—Alloys of iron and manganese such as Spiegeleisen and ferromanganese, are now largely made for use in the steel works, and for this purpose large quantities of manganese ores are imported. These ores are black in colour, and consist of one or more of the oxides of manganese, MnO_2 , Mn_3O_4 , or Mn_2O_3 , associated usually with oxide of iron. The principal localities from which these ores are obtained are the United States (principally Michigan and Wisconsin), Brazil, India, and smaller quantities from Greece, Spain, and Germany. The British output is very small.

Hæmatite.—Red hæmatite, which is the base of a most important series of iron ores, consists essentially of anhydrous ferric oxide (Fe_2O_3), and occurs of various shades of colour, from deep red to steel-grey, with a crystalline, fibrous, columnar, botryoidal, or amorphous structure; the ores occur further in both the earthy and the compact form, as also soft or hard, etc. From the variety of their physical characters the red hæmatites have received special names; thus, the crystalline variety, occurring at Elba, Brazil, etc., is known to the mineralogist as specular-iron ore or iron-glance, and possesses a bluish or steel-grey colour; it crystallises in the rhombohedral system, yielding a red streak, and containing, when pure, 70 per cent. of metallic iron. The scaly, micaceous, or foliated variety, which is used as the basis of a paint for iron work, is known as micaceous iron-ore; and when red hæmatites assume the form of dull, hard, compact masses, often reniform or kidney-shaped, as occurring in Cumberland, they are then known as kidney ore. The soft and more earthy varieties constitute red ochre, whilst puddler's-mine or ore is the soft, unctuous, compact, earthy form employed for the making and repair of the bottoms of puddling furnaces.

The hæmatite iron ores, owing to their freedom from sulphur and phosphorus, have been in great demand since the intro-

duction of the Bessemer steel process for the manufacture of Bessemer or Hæmatite pig-iron, but hæmatites containing quantities of both phosphorus and sulphur occur in various parts of the world.

The following table shows the average composition of some of these ores :—

ANALYSES OF RED HÆMATITE IRON ORES.

	A	B	C	D
Ferric oxide (Fe_2O_3) . .	94·88	86·50	94·23	85·037
Manganous oxide (MnO) . .	0·04	0·21	0·23	—
Alumina (Al_2O_3) . .	0·07	—	0·51	—
Lime (CaO)	0·34	2·77	0·05	—
Magnesia (MgO) . .	trace	1·46	trace	—
Silica (SiO_2)	4·55	—	—	5·130
Carbonic anhydride (CO_2) . .	—	2·96	—	—
Phosphoric „ (P_2O_5) . .	0·03	trace	trace	0·032
Sulphuric „ (SO_3) . .	—	0·11	0·09	—
Sulphur (S)	—	—	—	0·075
Pyrites (FeS_2)	0·47	—	0·03	—
Water (H_2O)	—	—	0·56	—
Organic matter	—	—	—	—
Insoluble residue	—	6·55	5·18	—
	—	100·56	100·88	—
Metallic iron per cent. . .	66·42%	60·55%	65·98%	59·526

A.—Barrow-in-Furness (Richards). B.—Ulverstone (Dick). C.—Ulverstone (Spiller). D.—Canadian.

In the North Lonsdale district the ores average from 52 to 54 per cent. of metallic iron, the highest yielding from 60 to 62 per cent., whilst the poorest contain about 40 per cent.

The most important deposits of red hæmatite are found in the Cambrian, Silurian, Devonian, and Carboniferous rocks ; the deposits of North Lancashire and Cumberland occur in veins in the limestone and Silurian systems, and at Eskdale in granite. Red hæmatite is often associated with the brown oxides, and the ore is classed as hard or soft, according as it contains free silica in excess or otherwise. The more important Continental and foreign deposits of these ores occur in Spain, Canada, and the United States.

Brown Hæmatite.—Brown hæmatite (limonite), or brown

iron-ore, is when pure a hydrated ferric oxide, represented by the formula $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, and would thus yield 59·89 per cent. of metallic iron. It has a dull lustre, and varies from blackish- to yellowish-brown, but it affords an invariable yellowish-brown streak. It occurs in irregular, compact, more or less homogeneous masses, in the Carboniferous limestone and lower Coal Measures of the Forest of Dean, Gloucestershire, and Glamorganshire; whilst a less pure variety, containing more or less mechanically mixed sand, occurs in the Lias, Oolites, and Lower Greensands of Northamptonshire, Lincolnshire, Buckinghamshire, and Oxfordshire; and in all these districts they are oxidised carbonates. Brown hæmatites also are among the most important of the ores smelted in France and Germany. "Bog-iron-ore" is an impure brown hæmatite, smelted in many localities. Associated with limonite, and included under the name brown ores, are göthite ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) and turgite ($2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$).

ANALYSES OF BROWN HÆMATITE IRON-ORES. ¹

	A	B	C	D	E	F
Ferric oxide (Fe_2O_3)	90·05	59·05	56·20	60·72	67·80	60·94
Manganous oxide (MnO)	0·08	0·09	0·20	—	·28	—
Alumina (Al_2O_3)	0·14	trace	2·43	11·175	10·19	8·03
Lime (CaO)	0·06	0·25	0·49		2·80	1·60
Magnesia (MgO)	0·20	0·28	0·17		·59	·06
Silica (SiO_2)	0·92	34·40	29·09	12·66	8·60	13·24
Phosphoric anhy- dride (P_2O_5)	0·09	0·14	0·84	trace	—	1·02
Sulphuric anhy- dride (SO_3)	—	—	—	—	—	·08
Sulphur	traces	—	—	0·075	—	—
Pyriets (FeS_2)	—	0·09	—	—	—	—
Water (combined)	9·22	6·14	10·90	13·77	15·35	15·35
„ (hygroscopic)	—	0·24		1·60		
Metallic iron per cent..	63·04	41·34	39·34	42·5	42·64	42·66

A.—Forest of Dean (Dick). B.—Glamorganshire (E. Riley). C.—Northamptonshire (Percy). D.—New South Wales. E.—Antrim. F.—Lincolnshire.

As previously mentioned, brown hæmatites vary much, both as regards the percentage of metallic iron which they

contain, and also in their freedom from such impurities as phosphorus and sulphur, whilst manganese is almost always present in those ores, and they are accompanied by more or less earthy matter.

Titaniferous iron-ore, or Ilmenite, occurs massive, but is found generally as a dark-coloured or black sand along the shores of the Bay of Naples, the North-east coast of America, Labrador, New Zealand, etc. Certain ferruginous crystalline rocks having been disintegrated, the lighter portions are washed away, whilst the heavier titaniferous particles, or grains, constituting the bluish iron sands, accumulate upon the shore in sufficient quantity to be collected, and, after a preliminary mechanical treatment, to be smelted for the production of iron. The titaniferous sands contain a large proportion of magnetite, besides titaniferous iron-ore, and these are usually accompanied by free silica, with more or less magnesia. Titaniferous iron-ore is a most refractory mineral, and when in a fine state of division is difficult to treat in the blast furnace.

Carbonate Ores.—Ferrous carbonate, FeCO_3 , is abundant as an iron mineral, and in admixture with various foreign matters forms valuable ores of iron.

The purer varieties are described as spathic ores, whilst the amorphous argillaceous ores of the Coal Measures are known as clay ironstones, and when largely impregnated with carbonaceous or bituminous matter they constitute blackband ironstone.

Spathic Ore.—Spathic ore in its purest form constitutes the crystallised mineral known as siderite, which, when pure, yields 48·27 per cent. of metallic iron. Siderite occurs as a mineral having a pearly lustre, and varying from yellow to brown in colour. but when it occurs in veins exposed to water and atmospheric influences, it is usually found to have suffered decomposition, and to have become converted into brown hæmatite to a considerable depth from the surface. Spathic ores often contain considerable quantities of manganous oxide, as is the case with the spathic ore of the Brendon Hills, in Somersetshire, which was at one time transported to Ebbw Vale, South Wales, to be smelted for the production of the manganiferous pig-iron known as spiegeleisen. The other more important associates of spathic ores are calcium and

magnesium carbonates, with occasionally also quartz, with copper and lead in small proportion. This ore occurs in the Carboniferous rocks of Durham, Cornwall, Devon, and Somersetshire, but more largely on the Continent, as in the mountain masses of Siegen and Musen, in Rhenish Prussia, where it is found in rocks of Devonian age; at Thuringia, in Hungary, it occurs in Permian rocks; whilst extensive deposits also are present in Styria, Westphalia, Lölling, and Carinthia, in Austria, as also in Hanover and in Russia.

ANALYSES OF SPATHIC AND OTHER IRON ORES.

	A	B	C	D
Ferrous oxide (FeO) . .	43·84	45·86	40·77	39·92
Ferric oxide (Fe ₂ O ₃) . .	0·81	0·40	2·72	3·60
Carbonic anhydride (CO ₂) . .	38·86	31·02	26·41	22·85
Manganous oxide (MnO) . .	12·64	0·96	—	0·95
Alumina (Al ₂ O ₃) . .	—	5·86	—	7·86
Lime (CaO) . .	0·28	1·37	0·90	7·44
Magnesia (MgO) . .	3·63	1·85	0·72	3·82
Potash (K ₂ O) . .	—	—	—	0·27
Silica and insoluble residue	0·08	10·68	—	8·76
Clay . .	—	—	10·10	—
Phosphoric anhydride (P ₂ O ₅)	—	0·21	—	1·86
Pyrites (FeS ₂) . .	—	0·10	—	0·11
Water (OH ₂) . .	0·18	1·08	1·00	2·97
Organic matter . .	—	0·90	17·38	—
	100·32	100·29	100·00	100·41
Metallic iron per cent. .	34·67	35·99	33·57	33·62

A.—Spathic ore, from Somersetshire (Spiller). B.—Clay ironstone from Dudley (Dick). C.—Blackband, Scotland (Colquhoun). D.—Cleveland Ironstone (Dick).

Clay ironstone is the argillaceous, amorphous, compact, or earthy variety of ferrous carbonate, occurring either in detached nodules, or in layers of nodular concretions, distributed through the shales and clays of the Coal Measures, or in beds of considerable thickness in Liassic rocks. These consist of ferrous carbonate mixed with a considerable quantity of clayey matter, or perhaps rather are beds of clay which have become saturated with carbonate of iron. The iron may be evenly distributed through the bed, or it may be collected into concretionary masses. When not discoloured by

admixture with carbonaceous matters or by atmospheric decomposition, they range in colour from light grey or yellow to brown, but the lighter coloured varieties rapidly become brown on exposure to the atmosphere; they are always impure, containing in addition to the clay appreciable quantities of calcium, magnesium, and manganese carbonates, phosphoric acid, iron pyrites (FeS_2), and occasionally also other minerals, as blende (ZnS) and galena (PbS). The principal localities in which they occur are the Coal Measures of North and South Staffordshire, Derbyshire, Yorkshire, Warwickshire, Shropshire, North and South Wales, Denbighshire, and in Scotland.

Blackband ironstone is ferrous carbonate associated with from 15 to 25 per cent. of bituminous, coaly, or other carbonaceous matter, which gives it almost the appearance of coal—it is, in fact, a bed of coal which has become saturated with ferrous carbonate; it occurs in beds most largely in the coalfields of Lanarkshire and Linlithgowshire, to a smaller extent in North Staffordshire, and also in South Wales. Owing to the large amount of carbonaceous matter contained in this ore, it can be calcined in heaps without the addition of any further fuel, and the calcined product yields from 50 to 60 per cent. of metallic iron.

Other earthy and metallic impurities are always present, and the ore always contains a considerable quantity of phosphorus. Black band ores were discovered in Scotland by Mushet, in 1801, and when the hot blast was introduced they came rapidly into use and “made” the Scotch iron industry. The Scotch deposits are now almost exhausted.

Cleveland Ironstone.—This is one of the most important ores now raised in this country. It was first worked about 1850, and it has led to the development of Middlesbrough into the most important iron-producing district in the country. It is an impure carbonate, the carbonate being associated with calcium carbonate and other earthy matters. The beds seem to be beds of an oolitic limestone in which the calcium carbonate has been replaced by ferrous carbonate. The beds belong to the Liassic series. They are very fossiliferous, the two main beds being distinguished by the names of the predominant fossils, the *Avicula* and *Pecten* beds. The total thickness of the beds is about 15 ft. The mines are on

the Cleveland Hills, a few miles behind—that is, south of Middlesbrough—so that the ore can easily be brought down to the town.

The ore is more or less granular or oolitic in structure, and usually of pale bluish-green colour, due to the presence of ferrous silicate; but some varieties are darker. One bed at Rosedale Abbey, now exhausted, was very dark—nearly black—and was magnetic from the presence of magnetic oxide. One of the most important characters of the ore is the large quantity of phosphorus always present, owing to the very fossiliferous character of the rock. Ores very similar in character to those of Cleveland are now being worked in other places. The readiness with which the carbonate passes into the hydrate under the influence of air and moisture has already been explained, and in many cases where surface deposits of brown ore have been worked through, carbonate has been found underlying. This has been the case in Northamptonshire. In Lincolnshire extensive beds of fossiliferous carbonates of the Lias age are now being worked, and an extensive iron industry is growing up there in consequence. The ores are high in phosphorus, yellow and green in colour, and are not unlike those of Cleveland. The workable beds are about 16 ft. in thickness

Imported Iron Ores.—With the introduction of the Bessemer process for steel-making there arose a great demand for pig iron free from sulphur and phosphorus, and this could only be made from ores free from these elements. As the only British deposits of suitable material—those of North Lancashire and Cumberland—were quite inadequate to meet the demand, ironmasters had to seek other sources of supply. The enormous development of the iron industry during the last thirty or forty years has also necessitated a supply of ore greater than the home mines could yield, so that the world has been searched for suitable ore deposits, and an immense import trade in iron ore has grown up.

Among the most important of the districts supplying iron ore is Bilbao, in Spain, from which district about 8,000,000 tons of ore is annually exported. The ores are red and brown hæmatites and carbonates, the brown ore being due to surface oxidation of the deeper-lying carbonate. Four varieties of ore may be mentioned :—

(1) Vena.—A dark purple ore, very soft, and yielding about 60 per cent. of iron. It occurs only in small quantity.

(2) Campanil.—A dark red ore, yielding about 55 per cent. of iron, the gangue being mainly carbonate of lime. This ore has been largely used both for smelting and in the open-hearth steel furnace, but the supply is now nearly exhausted.

(3) Rubio.—A brown or yellow ore occurring in lumps which often have a vesicular structure. Being a brown ore, it contains a considerable quantity of water, and yields about 50 per cent. of iron. The gangue is siliceous.

(4) The carbonate ore is now being largely worked. It has an oolitic structure, and is always calcined before export.

All these ores are free from sulphur and phosphorus. Iron ores occur, and are extensively worked, in many other parts of Spain: Carthagena, Almeida, Sevilla, Huelva, and other localities may be mentioned. The ores are sometimes black (magnetites), more often red (hæmatites), but generally brown ores, and they are usually free from sulphur and phosphorus. Iron ores are also imported from Canada, from Cuba, from Norway and Sweden, from Elba, and many other localities. Imported ores are not now always phosphorus-free, as for some purposes there is a demand for phosphoric ores.

The following analyses will give an idea of the character of the imported ores:—

	A	B	C	D	E	F
Iron . . .	58·80	55·49	68·50	48·26	58·61	46·56
Manganese . . .	1·47	·70	Trace	3·51	—	1·82
Silica . . .	3·20	8·88	2·50	7·00	5·42	3·08
Lime . . .	4·60	Trace	—	2·44	—	8·22
Sulphur . . .	—	·012	·040	·017	·276	·046
Phosphorus . . .	Trace	·012	·018	·014	·017	·016
Copper . . .	—	—	—	—	—	·019
Moisture . . .	6·00*	10·30	Trace	2·50	1·50	6·50

A.—Campanil. B.—Rubio. C.—Gellivara. D.—Almeira, Spain.
E.—Mokla, Algeria. F.—Seriphos, Greece.

* And carbon dioxide.

Output and Consumption of Ore in the United Kingdom.
—In order that the student may understand to what extent Great Britain is at present dependent on foreign ore supply

and the wide field from which this is derived, the following figures for the year 1904 are given :—]

The total amount of iron ore raised in Great Britain was 13,774,282 tons, of which the output was from :

	TONS.
Cleveland	5,758,510
Scotland	838,104
Staffordshire	818,468

The ore imported, including chrome ore, was from :—

	TONS.
Sweden	238,256
Norway	281,862
Germany	2,534
Holland	11,450
Belgium	9,410
France	172,950
Portugal	6,045
Spain	4,648,355
Italy	—
Greece	344,555
Turkey, European	6,961
Turkey, Asiatic	2,802
Algeria	237,744
Persia	2,441
United States	5,317
Other Foreign Countries	79,145
Total from Foreign Countries	6,649,807

From British Possessions :—

Australia :	
Victoria	78
New South Wales	4,115
Canada	22,290
Newfoundland	18,217
Other British Possessions	6,429
Total from British Possessions	51,129

Total imports from all sources, 6,700,746 tons, or, roughly speaking, of the total ore used about one-third is imported. If it were measured by the amount of iron produced the proportion would be much larger, since the imported ores are in general much richer in iron than those raised at home.

In the year 1904 the amount of manganese ore imported

was 205,175 tons, of which 95,840 tons came from Russia, 52,620 tons from Brazil, and 27,970 tons from India, whilst only 3,971 tons came from Greece.

American Iron Ores.—The immense development of the American iron industry during the last twenty-five years has been largely due to the discovery of immense deposits of rich and easily-worked iron ores. Iron ores of all kinds are widely distributed in the United States, but, as a rule, only the richer varieties, such as magnetites and red and brown ores are smelted. The most important ores at present worked are the hæmatites of the Lake Superior District, about 75 per cent. of the iron made in the United States being made from these ores. The ores come to the surface in thick beds, and are often worked by quarrying, steam navvies being largely employed to lift the ore and transfer it to the railway trucks.

In the year 1903 the output in the Lake Superior district was :

	TONS.
From the Marquette Range	3,040,245
„ Menominee „	3,749,567
„ Gogebic „	2,912,912
„ Vermillion „	1,674,699
„ Mesabi „	12,892,542
Total	<hr/> 24,271,965

the total output of the United States for the year being 32,471,550 tons. The ores are low in sulphur and phosphorus, and the iron is made of the Bessemer or Hæmatite quality. In the Southern States hæmatite ores occur which contain phosphorus, and are therefore used in the manufacture of foundry pig.

Classification of Iron Ores.—Iron ores may be classified in various ways. A convenient classification is that based on the mineral which forms the basis of the ore :—

Black ores	contain Magnetite.
Red ores	„ Hæmatite.
Brown ores	„ Limonite.
Carbonate ores	„ Carbonate.

For practical purposes ores are often classified into non-phosphoric and phosphoric. Non-phosphoric ores are such

as contain less than .06 per cent. of phosphoric anhydride, such as the Cumberland and North Lancashire Hæmatites, Bilbao ores, etc. Phosphoric ores contain more than .60 per cent. of phosphoric anhydride, such as Cleveland ores, Blackland ores, Clayband ores, etc. Or they may be classified according to the nature of the gangue associated with the iron mineral :—

(1) Siliceous Ores.—Those in which the gangue is mainly silica—*e.g.* the Cumberland, North Lancashire Hæmatites, most Spanish ores, etc.

(2) Calcareous Ores.—In which the gangue is mainly carbonate of lime—*e.g.* Campanil ore.

(3) Aluminous Ores.—In which the gangue is mainly alumina—*e.g.* Belfast aluminous ore.

(4) Argillaceous Ores.—Those in which the gangue is mainly clay—*e.g.* Clayband ores.

(5) Bituminous Ores.—Those in which the gangue contains a large quantity of bituminous or coaly matter—*e.g.* Blackband ores.

This classification is very convenient for smelting purposes.

CHAPTER IV.

METALLURGICAL CHEMISTRY OF IRON.

PURE metallic iron, as already stated, is a body difficult of preparation, especially in the compact state, except by laboratory methods, and the pure metal is not therefore a substance of commercial importance; but in combination with variable but small proportions of carbon, and other metallic and non-metallic elements, such as sulphur, silicon, phosphorus, manganese, etc., it constitutes the various qualities of pig-iron, steel, and malleable-iron. The chemical symbol for iron is Fe, and its atomic weight is 56.

Pure iron is prepared by the electrolysis of ferrous chloride (FeCl_2), by the reduction of ferric oxide (Fe_2O_3), or of ferrous chloride, by heating either of them to redness in a tube through which a current of hydrogen gas is passed; or in a nearly pure state it can be obtained by the fusion under a layer of glass free from metallic oxides, of fine iron wire or iron filings, with artificially-prepared magnetic oxide of iron. Iron as prepared by the last method is a metal varying in colour from bluish-grey to silver whiteness according to the state of its aggregation; as reduced from ferric oxide by hydrogen, it forms a grey powder, which is pyrophoric (that is, takes fire spontaneously on exposure to the atmosphere) if the temperature employed in its production has not exceeded dull redness; but it no longer possesses this quality if the temperature employed in its preparation has exceeded this limit. As obtained from ferrous chloride (FeCl_2), the metal yields well-defined cubical crystals, and it is always crystalline after fusion. Iron is capable of receiving a high polish, it is very tenacious, ductile, and malleable, the last quality being unaffected by heating and subsequent rapid cooling, neither is it hardened by this treatment: Electro-deposited iron absorbs or occludes hydrogen to the extent of from seventeen to twenty times its own volume.

Magnetism of Iron.—One of the most striking properties of iron, in which it excels all other elements, is its power of becoming magnetic. If a piece of nearly pure iron be brought into a magnetic field, it at once becomes magnetic to a much higher degree than the field in which it is placed. Its magnetic permeability is therefore said to be high. It seems to concentrate the surrounding magnetism into itself. Immediately it is taken out of the magnetic field the magnetic power is lost—that is, it is not retained by the iron, or its magnetic retentivity is almost nil. At a high temperature—about a red heat—the magnetic permeability is completely lost, and the iron ceases to be magnetic. The presence of foreign elements in the metal greatly modifies its magnetic properties. A small percentage of carbon decreases the permeability, but increases the retentivity, so that permanent steel magnets can be made, whilst a considerable percentage of manganese destroys both properties.

Pure iron is softer than the commercial varieties of malleable iron, and has a specific gravity of 7.87. Its melting point does not appear to have been accurately determined, for whilst Pouillet estimates it at from $1,500^{\circ}\text{C.}$ to $1,600^{\circ}\text{C.}$ ($2,732^{\circ}\text{F.}$ to $2,912^{\circ}\text{F.}$), Scheerer gives it as $2,100^{\circ}\text{C.}$ ($3,812^{\circ}\text{F.}$), but the presence of small quantities of carbon in combination with the metal rapidly lowers the melting point.

Iron is unaffected by dry air at ordinary temperatures (except in the pyrophoric or spongy state already described), or in perfectly pure water free from air, oxygen, or carbonic anhydride; but if exposed to a moist atmosphere, then the oxidation commonly known as rusting rapidly proceeds, if carbon-dioxide is also present, as it always is, in the atmosphere. The presence of carbon-dioxide appears essential to the rusting of the iron by moisture, since the metal may be kept bright for almost any length of time in pure lime water, or in a solution of soda. Under the joint influence of moisture, oxygen, and carbon-dioxide, ferrous carbonate is first produced on the surface of the iron, but this, by absorbing a further proportion of water and oxygen, becomes changed to a hydrated ferric oxide, with the liberation of carbon-dioxide, which latter then reacts upon a fresh portion of the iron in the presence of water and oxygen, and a further quantity of ferrous car-

bonate is produced, and so the cycle continues to be repeated. Further, the hydrated oxide, or rust, is electro-negative with respect to the metallic iron upon which it is formed, and the electrical condition thus resulting still further promotes the action of oxygen on the metal, and the corrosion of the iron thus proceeds rapidly. Water holding carbon anhydride and free oxygen in solution rapidly attacks and oxidises metallic iron. Iron, when heated to redness in contact with air or oxygen, is rapidly oxidised, with the production of a black scaly oxide readily detachable from the surface of the iron. This oxide constitutes, on the large scale, the hammer-scale or hammer-slag of the forge, and is mainly the magnetic oxide Fe_3O_4 . Iron at a red heat decomposes water with the liberation of hydrogen and the formation of Fe_3O_4 .

Hydrochloric acid attacks metallic iron with the formation of ferrous chloride (FeCl_2) and the liberation of free hydrogen. Concentrated sulphuric acid (H_2SO_4) also attacks the metal with the liberation of sulphur-dioxide (SO_2), whilst ferrous sulphate (FeSO_4) crystallises out; but if the diluted acid be employed, then hydrogen is liberated, and ferrous sulphate remains in solution. The action of nitric acid upon iron, at the ordinary temperature, varies with the degree of concentration of the acid. Thus, ordinary nitric acid attacks iron vigorously with the evolution of nitrous fumes in abundance, but if the acid be dilute there is no sensible escape of gas, and ferrous nitrate $\text{Fe}(\text{NO}_3)_2$ and ammonium nitrate (NH_4NO_3) occur in solution; thus $10\text{HNO}_3 + 4\text{Fe} = 4\text{Fe}(\text{NO}_3)_2 + \text{NH}_4\text{NO}_3 + 3\text{H}_2\text{O}$ strong-fuming nitric acid is without action upon the metal, a bright surface of which may be introduced into the cold concentrated acid without inducing any chemical decomposition, in which case the surface of the metal on immersion assumes a dull whitish appearance, and no further action ensues, the metal having assumed what is known as the passive condition.

Iron Oxides.—Four oxides of iron are known. Corresponding hydrates of some of them exist, and two form the starting point of a series of salts. The important oxides are the ferrous oxide (FeO), ferric oxide (Fe_2O_3), and the intermediate black oxide (Fe_3O_4).

Black oxide (Fe_3O_4) is a magnetic substance obtained by heating iron to redness in steam. Hammer-scale, obtained by heating iron in air, is not uniform in composition or physical character. The outer layer of scale is found to be strongly magnetic, almost metallic in lustre, brittle, fusible only at the highest temperatures, more highly oxidised, and somewhat redder in colour than the inner layers, which are less lustrous, spongy, tougher, and less magnetic than the outer layers. Magnetic oxide (Fe_3O_4) is the oxide of iron entering most largely into the composition of the scale, but there is also a variable excess of ferric oxide (Fe_2O_3), and hence the varying physical qualities of the scale. Magnetic oxide occurs native as the black mineral known as magnetite.

When the magnetic oxide is dissolved in acids a mixture of ferrous chloride (FeCl_2) and ferric chloride (Fe_2Cl_6) results, the proportion of the two salts being the same as that of the oxides in the substance dissolved.

Magnetic oxide is sometimes regarded as being a mixture or molecular combination of the other two oxides.

Ferric oxide (Fe_2O_3) is a very stable and practically fixed oxide of iron, decomposable, however, at a white heat, with the liberation of oxygen and the production of the magnetic oxide ($3\text{Fe}_2\text{O}_3 = 2\text{Fe}_3\text{O}_4 + \text{O}$). Ferric oxide is produced when ferrous sulphate is strongly heated, the salt suffering decomposition with the elimination of sulphur-dioxide (SO_2) and sulphuric anhydride (SO_3), whilst a bright red pulverulent powder, forming the rouge or colcothar of commerce, is obtained, which has the composition of ferric oxide. Ferric oxide is decomposed with the reduction of metallic iron by heating it in a current of carbonic oxide (CO) or hydrogen, or by heating it with carbon. Ferric oxide after ignition is only slowly acted upon by either hydrochloric, nitric, or sulphuric acid, but previous to ignition it is readily soluble in these acids with the production of stable ferric salts; if heated with an excess of sulphur, sulphur-dioxide (SO_2) is evolved, and ferrous sulphide (FeS) is obtained.

Ferric oxide is prepared in the laboratory by heating to redness ferrous nitrate, oxalate or sulphate, or a mixture of ferrous sulphate and sodium chloride; whilst it occurs in

nature in sufficient abundance to be worked as the mineral hæmatite.

The hydrated ferric oxide ($2\text{Fe}_2\text{O}_3, 3\text{H}_2\text{O}$) is the most stable of the hydrated oxides of iron, and occurs native as brown hæmatite or limonite. The freshly precipitated oxide obtained by adding potash, soda, or ammonia, to a solution of a ferric salt, is an amorphous, brownish-red body, readily soluble in acids, and even slightly soluble in water containing carbon-dioxide in solution, and having the composition $\text{Fe}_2\text{O}_3, 3\text{H}_2\text{O}$, but after remaining precipitated for some time, or by boiling with water during six or seven days, it loses two equivalents of its water of composition, retaining but one equivalent, assuming thereby a more brick-red colour, and becoming only slightly soluble in the mineral acids.

Iron rust is essentially hydrated ferric oxide of variable composition, produced on the exposure of metallic iron to the joint action of air, water, and carbon-dioxide.

Ferrous oxide (FeO) is of little metallurgical importance. It is a very unstable body, and even if it has ever been obtained pure oxidises so readily that it is of no practical importance, but it is the starting point of the ferrous salts in which iron exists in the ferrous condition, such as the carbonate FeCO_3 , the sulphate FeSO_4 , etc. Clay-ironstone contains a large proportion of ferrous carbonate, and it exists in a still larger proportion in the crystallised ores such as siderite or spathic iron-ore. In combination with silica, it forms ferrous silicate ($2\text{FeO}, \text{SiO}_2$), which enters largely into the composition of the various slags, cinders, etc., produced in the metallurgical treatment of iron. The hydrated oxide or ferrous hydrate is precipitated as a white flocculent precipitate, when potash or soda is added to a solution of a ferrous salt; but the precipitate rapidly changes from white to green and then to brown, owing to the absorption of oxygen.

A fourth oxide is ferric anhydride, which in combination with water is known as ferric acid (H_2FeO_4), is not of metallurgical interest, since it has not been obtained in the free state. Its alkaline salts result in small proportion when nitre and iron filings, or nitre and ferric oxide, are heated to dull redness and are very unstable; they rapidly



and spontaneously decompose with the liberation of oxygen and the separation of ferric oxide.

Compounds of Carbon and Iron.—Iron and carbon combine readily under various conditions, and the importance of these combinations is so great commercially that they must be somewhat fully considered.

When iron is melted with carbon, as in the blast furnace, the carbon is absorbed until about 4·5 per cent. is present. The same result may be obtained, though more slowly, by heating iron to the welding temperature in presence of solid carbon, as in the cementation process of making steel. Indeed, carbon and iron combine so readily that it is almost impossible to prepare perfectly carbon-free iron.

Pig iron containing about 4·5 per cent. of carbon, the maximum which it can take up, is not a definite compound. Up to the present only one definite compound of carbon has been proved to exist— Fe_3C , which was discovered by Professor Abel, and is therefore often called “Abel’s Carbide,” which contains 93·23 per cent. Fe. and 6·67 per cent. C.

Another carbide— Fe_{24}C , containing ·89 per cent. carbon—has been suggested, but its existence has not been proved. If it is not a definite carbide, it is certain that carbon can exist to this amount in a state of solid solution in iron. Carbon exists in commercial forms of iron in at least three forms.

(1) **Graphite.**—When a mass of highly carburised iron—say a pig-iron containing about 4 per cent. of carbon—is allowed to solidify, at the moment of solidification, or immediately after the metal has become solid, a large proportion of the carbon may be ejected in the form of flat black, glistening flakes of graphite. It is certain that in the liquid metal all the carbon was either in solution or combination, or being so much lighter than the iron, it would have floated to the top, and as the flakes of graphite are very uniformly distributed the separation must have taken place after the mass had become so solid that the flakes could not float upward.

Such an iron would be a grey iron. Much of the carbon would be present in the form of graphite, which, if a sample of the iron were dissolved in acid, would be left in the insoluble residue, since graphite is unacted on by acids, whilst the small portion in combination would escape.

(2) **Combined Carbon.**—When a sample of steel is dissolved in acid there is no residue of graphite, the whole of the carbon present passing away in the gaseous form with the evolved hydrogen. The carbon is present, therefore, in the combined condition, and not in the form of graphite; but it is found, further, that the behaviour of the carbon in a steel to certain solvents may vary according to the character of the steel, and that the properties of the steel itself will vary very much according to which of the two forms the carbon is present in.

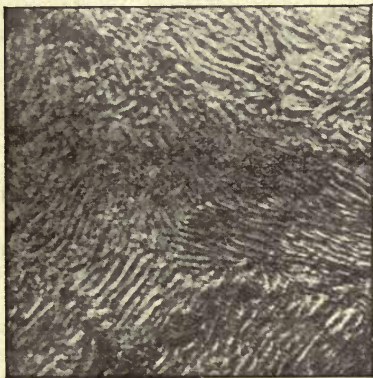


Fig. 12.—Pearlite Magnified about 500 Diameters.

Carbide Carbon.—When the steel is cooled slowly and then dissolved in some acid or other solvent which does not evolve hydrogen—a mixture of chromic and sulphuric acids being usually used—the carbon is left in the form of a definite carbide (Fe_3C), and carbon in this form is always spoken of as carbide carbon.

Hardening Carbon.—If the steel be heated to redness and then suddenly quenched, it becomes intensely hard, and if now it be dissolved as before, the carbon is not left as carbide, but disappears by oxidation or otherwise. As the carbon present in this form hardens steel it is called hardening carbon.

Thus carbon may exist in iron in three forms:—(1) Graphite. (2) Combined carbon (a) carbide carbon; (b) hardening carbon.

In order to learn more about these forms of combined carbon, other than purely chemical methods must be used, and in the microscope the necessary instrument has been found.

If a piece of iron containing about .89 per cent. of carbon and no other impurities be heated to redness and slowly cooled, and then be suitably polished, etched, and examined under the microscope, it is found to show a very peculiar structure (shown by Fig. 12). It is seen to be made up of a series of more or less parallel bands of two substances; the one, much harder than the other, resists abrasion and the action of etching agents much more strongly, and so stands up in relief.

Of these two substances—

(1) The harder one is the carbide (Fe_3C), or, as it is called in the language of metallography, Cementite. This is an intensely hard body.

(2) The softer one is pure iron, Fe, or, as it is known in this connection, Ferrite.

The compound body made up of the two is called Pearlite. Though pearlite seems to be only a mechanical mixture it has a definite composition, and contains .89 per cent. of carbon. As cementite contains 6.67 per cent. it is obvious that pearlite consists of about 13.35 per cent. of cementite and 86.65 per cent. ferrite. The percentage of cementite is the percentage of carbon $\times 15$.

The maximum amount of carbon which can be held by solid pure iron is about 4.5 per cent., but that amount may be increased by the presence of other constituents.

If the sample of metal be heated to redness, chilled in water, and then polished and etched as before, an entirely different structure is seen. The pearlite has disappeared. The metal looks almost structureless, but faint feathery crystals may be detected. The carbon here has not separated, but has remained distributed through the whole of the mass, probably in the form of a solution; and as the solvent iron in this case is solid and not liquid, it is called a solid solution. This form is called Martensite.

If now a sample of metal containing less carbon than .89—say .2 per cent.—of carbon be heated, slowly cooled, and etched as above described, and this examined, it will be found

that there are only small particles of pearlite, which are surrounded by masses of ferrite. It will be seen that there is not enough carbon to convert all the iron into pearlite, so that the balance will be left as ferrite. If the sample be quickly cooled, the sample will consist of Martensite, and perhaps ferrite.

If now a sample containing more than .89 per cent. of carbon—say with 1.2 per cent. of carbon—be slowly cooled, the main portion of the mass will be found to be made up of pearlite; but obviously there is now more than enough carbon to form pearlite. The excess will remain as fragments or filaments of cementite scattered through the pearlite.

Carbon, therefore, may be present in iron as—(1) Inter-mixed graphite. (2) Cementite in pearlite. (3) Cementite in excess of that required to form pearlite or structurally free cementite. (4) Martensite, which may or may not be associated with excess of cementite or ferrite.

The conditions under which the carbon can exist in each form, and the changes produced in the properties of iron by variations in the form in which the carbon is present will be discussed fully in the companion volume which treats on "Steel: its Varieties, Properties, and Manufacture."

Ferrous carbonate (FeCO_3) is metallurgically one of the most important salts of iron, since the anhydrous ferrous carbonate occurs crystallised as siderite or spathic iron ore, and in the other varieties of carbonate ores which have been described. On p. 40 it is explained how ferrous carbonate was produced by exposing iron to the joint action of atmospheric air or oxygen, moisture and carbonic anhydride (CO_2), and how by further exposure the ferrous carbonate was again decomposed, with the deposition of hydrated ferric oxide, or iron-rust. Ferrous carbonate is slightly soluble in water, but more so in water containing free carbon-dioxide, and this solution on exposure to the atmosphere suffers decomposition, with deposition of the hydrated ferric oxide as before mentioned. Ferrous carbonate is also decomposed at a red heat in the absence of air or oxygen, with the production of red oxide of iron and the liberation of carbon dioxide and carbon monoxide the $2\text{FeCO}_3 = \text{Fe}_2\text{O}_3 + \text{CO} + \text{CO}_2$, or if the temperature be higher with the production of magnetic oxide of

iron (Fe_3O_4), and the liberation of carbon-monoxide (CO) and carbon-dioxide, thus: $3(\text{FeCO}_3) = \text{Fe}_3\text{O}_4 + 2\text{CO}_2 + \text{CO}$.

Compounds of Sulphur.—Several sulphides of iron are known. The direct combination of sulphur and iron results when these elements are brought into contact under the influence of heat, the combination being attended with a considerable evolution of heat, ferrous sulphide (FeS) being formed.

Ferrous sulphide (FeS) is the ordinary sulphide of iron of commerce, but it does not occur free in nature. It can be prepared artificially, as previously mentioned, by the direct union of sulphur with iron at a red-heat; by heating to redness ferrous sulphate in a charcoal-lined crucible; by the ignition of hammer-scale with sulphur; or by the precipitation of a ferrous salt by an alkaline sulphide. As artificially prepared by the dry methods above enumerated, it forms a dark brown or black body, having a semi-metallic lustre. It is not sensibly affected by exposure to the atmosphere at ordinary temperatures; but, if heated, as in the operation of roasting, it is oxidised and ferrous sulphate and ferric oxide results. At a higher temperature, the ferrous sulphate is decomposed with the production of ferric oxide (Fe_2O_3) and the liberation of sulphur-dioxide and sulphur-trioxide. When heated with carbon, ferrous sulphide is but slightly acted upon; when heated with ferric oxide, part of the sulphur passes off as sulphur-dioxide, but there is no reduction of metallic iron. Ferrous sulphide is not affected by heating with silica alone, but if carbon be also present the ferrous sulphide is largely decomposed.

Iron Pyrites.—Iron disulphide (FeS_2) is a familiar brass-yellow mineral occurring in many forms, having a strong metallic lustre, and known generally as yellow iron pyrites, cubic pyrites, or mundic. It crystallises in the cubic system, good crystals being quite common. It also occurs massive in vast quantities, and is largely used under the name of sulphur ore for the manufacture of sulphuric acid. It is of no use directly as an ore of iron, but the residues left on burning the pyrites in the manufacture of sulphuric acid, known as blue billy or burnt ore, or after the copper has been extracted as purple ore, are used in the ironworks. Marcasite

or white iron pyrites, has the same composition as iron pyrites, from which it differs by its pale colour and its different crystalline form. Heated without access of air, either form of disulphide is decomposed, sulphur being evolved, and a sulphide of uncertain composition left: $2\text{FeS}_2 = \text{Fe}_2\text{S}_3 + \text{S}$ or $\text{FeS}_2 = \text{FeS} + \text{S}$. In presence of air the sulphur is oxidised, thus: $2\text{FeS}_2 + 11\text{O} = \text{Fe}_2\text{O}_3 + 4\text{SO}_2$; or at lower temperatures, $\text{FeS}_2 + 6\text{O} = \text{FeSO}_4 + \text{SO}_2$, the iron sulphate being decomposed on further heating. Both pyrites and marcasite are oxidised on exposure to moist air, various products, such as ferric oxide or ferric sulphate, sulphuric acid, etc., being formed. Marcasite oxidises far more readily than pyrites.

Magnetic pyrites or pyrrhotine (Fe_3S_4) occurs native, associated with the ores of nickel and copper, but it has no special metallurgical importance.

Iron and phosphorus readily unite under the influence of heat, producing grey fusible phosphides. A ferrous phosphide results when ferrous phosphate is heated to a high temperature with carbon.

Of the various phosphides of iron that can be prepared by purely chemical methods only one—that having the formula Fe_3P and containing 15.58 per cent. of phosphorus, is of any metallurgical importance. This phosphide dissolves in metallic iron, and if there be less than about 1.7 per cent. of phosphorus, the iron will retain this in solid solution. The presence of such phosphorus tends to produce crystals of large size. If the quantity of phosphorus be above 1.7 per cent., the excess of phosphide will separate as a definite eutectic containing about 10 per cent. of phosphorus and melting at about 980°C . This eutectic consists of the phosphide Fe_3P and metallic iron, and of course can be detected under the microscope. The amount of phosphorus than can be held in solution is very much modified by the presence of other elements, and will be discussed when cast-iron is being considered. When iron containing phosphorus is treated with hydrochloric acid a portion of the phosphorus is eliminated as phosphoretted hydrogen, PH_3 .

Eutectic.—When an alloy of two or more metals solidifies, changes other than a mere solidification usually take place, though the exact character of the changes will depend on the

metals present. For example, assume the alloy to consist of two elements, A and B, the quantity of B being larger than A can retain in solution in the solid condition. Then as solidification goes on, A with some B in solution will solidify and some B will be thrown out, so the mother liquor is growing constantly richer in B. At last a point is reached when the two constituents of the mother liquid will solidify together. They will then so solidify, not as one substance, but as layers or masses of the two separate substances, forming a eutectic. The eutectic mixture is the alloy of lowest melting point of the series. In structure it often closely resembles pearlite. Though pearlite has this distinctly eutectic structure, it is not a eutectic, because it is not formed during solidification, but after the metal has actually become solid.

Iron and Silicon.—Silicon and iron unite in various proportions, and definite silicides are known. The silicide dissolves readily in metallic iron, and when silicon is present in an iron it is present in solid solution in the ferrite, and therefore cannot be detected by the microscope. Silica is always present in furnace charges, and being partially reduced at the temperature of the furnace, silicon passes into the iron. There does not seem to be a definite limit as to the quantity of silicon which can be taken up under suitable conditions. Irons containing 15 per cent. or more of silicon are regularly made.

Silica and ferrous oxide, or ferric oxide, in presence of reducing agents, unite readily, forming ferrous silicates. Of the silicates the most fusible and probably the most stable is the monosilicate ($2\text{FeO}, \text{SiO}_2$), Fe_2SiO_4 . This is fusible at a bright red heat, and solidifies to a black, more or less glassy mass. It constitutes a large proportion of the slags produced in puddling and similar operations, and in the smelting of lead and copper ores in the blast furnace. When this silicate is roasted with free access of air, it is broken up into ferric oxide and silica ($\text{Fe}_2\text{SiO}_4 + \text{O} = \text{Fe}_2\text{O}_3 + \text{SiO}_2$), and as these do not unite, a refractory mixture called Bull Dog results. In a reducing atmosphere, however, the ferric oxide is reduced to the ferrous condition, and the fusible silicate is reproduced. The silicates containing less iron, such as the bisilicate (FeO, SiO_2), FeSiO_3 , are rarely produced in metallurgy.

Iron and nitrogen unite to form two or more distinct

nitrides of iron. When iron-wire is heated to redness for some hours in a current of dry ammoniacal gas, the wire so treated is stated to gain slightly in weight, to be more brittle, and less alterable by exposure to the atmosphere than pure iron, and to become also whiter in colour; Savart says that after attaining to this condition, if it be longer exposed to the ammoniacal vapour, the metal assumes a dark-grey colour, becomes soft, has a graphitic fracture, and will not harden in water. The evidence as to the exact increase in weight of the iron by the above treatment is very contradictory, the statements ranging between 0·2 to 12 or 13 per cent., and from such evidence it is impossible to state whether nitrogen does or does not play any important part in the process of cementation for the conversion of bar-iron into blister-steel.

Whether nitrogen exists in combination in iron is very uncertain. Nitrogen can usually be obtained from iron, but it is probably present merely in the form of dissolved gas. At any rate, it does not appear to have any influence on the quality of the metal.

Alloys.—Iron and many of the other metals unite with great facility to form alloys; thus, for instance, when the ores of iron and of a second metal are simultaneously reduced, an alloy of the two metals often results, though with but few exceptions these alloys are without commercial importance.

Manganese is a constant constituent of pig-iron and of steel, and the metals seem to alloy in all proportions. Spiegeleisen is a pig-iron containing from 8 to 30 per cent. of manganese, and is a regular article of commerce; whilst alloys known as ferro-manganese, containing from 80 to 85 per cent. of manganese, are manufactured in large quantities for use in the production of mild steel, by the Bessemer and Siemens processes. The presence of manganese in iron ores favours the elimination of sulphur from the pig-iron produced from such ores.

Tungsten and iron unite readily, when tungsten is reduced from its compounds by carbon in the presence of metallic iron, but a very high temperature is required for the reduction.

Chromium alloys with iron, producing ferrochrome, which is now made on a large scale, containing up to about

65 per cent. of chromium. This alloy is used in the preparation of chrome steel.

Copper does not readily unite with iron to produce a homogeneous alloy by the simple fusion of any mixture of the two metals, but if iron be added in small quantities to brass or bronze in a state of fusion it is readily taken up, and the resulting alloy has a higher tensile strength than the original brass. Copper in small quantities does not seem to have any injurious influence on iron, whether it is to be used in the foundry or for steel making.

Zinc and iron yield, when heated together, more or less crystalline, brittle, and friable alloys, which, however, are without practical application to the arts, and are more properly zinc alloys, since about 7 per cent. is the maximum amount of iron that molten zinc will take up; but the manufacture of galvanised or zinced plates—that is, steel plates coated with a thin layer of zinc, or with an alloy of zinc and iron—is now in itself an important industry. Galvanised plates, whilst possessing the strength due to the steel, are not so readily affected on exposure to atmospheric influences by rusting or corrosion, so long as the zinc coating remains intact.

Tin and iron unite when heated together, and produce grey or white alloys, which are harder than tin, and break with a crystalline or granular fracture. Alloys of the two metals in almost any proportions may be obtained, but like the alloys of zinc, they are also without practical application to the arts, but a layer of metallic tin is readily applied to an iron or steel surface as in the manufacture of tin plates. Small quantities of tin in malleable-iron or steel render it cold-short, and also only workable with great care even at a red-heat, the metal being brittle and difficult to weld.

Antimony can be readily alloyed with iron, but its presence in wrought-iron, to the extent of only 0·2 or 0·3 per cent., is sufficient to render the iron both red-short and cold-short.

Nickel alloys readily with iron, by the direct fusion of the two metals, or by reducing a mixture of their oxides. The presence of nickel in iron does not affect its malleability, but the alloy is whiter in colour than pure iron, is not so easily affected by exposure to air or moisture, and takes a better polish than iron. A native alloy of nickel and iron with other metals occurs in the meteoric masses which are occasionally

found. Steel containing a considerable percentage of nickel is now regularly made.

Cobalt also readily alloys itself with iron, producing similar alloys to those last described; small quantities do not produce any material alteration in the physical or working qualities of the iron or steel.

Lead does not appear to unite with iron when the two are melted together, and no satisfactory alloy has been described of these metals.

Aluminium yields, with iron, alloys of various composition, and the alloy known as ferro-aluminium is used to some extent in steel making.

Silver does not appear to unite with iron when melted along with it, for when the mixture cools the silver is found to have separated throughout the mass, and not to have produced any homogeneous alloy.

Gold alloys itself readily with iron, upon simple fusion together of the two metals, the alloy being harder than malleable iron.

Platinum alloys with iron without difficulty, the melting-point of the alloy being below that of steel. Steel containing 1 per cent. of platinum is tough, fine-grained, tenacious, and ductile. Similar alloys are also obtainable by the substitution of small quantities of the rarer metals palladium and rhodium.

CHAPTER V:

CAST-IRON OR PIG-IRON:

PIG-IRON is the product formed by treating iron ores with fuel and fluxes in the blast furnace. It is an impure iron containing carbon, silicon, sulphur, phosphorus, manganese, and often with smaller quantities of other metals, such as arsenic, titanium, copper, chromium, etc.

Owing to the high temperature of the blast furnace the iron always takes up nearly the maximum amount of carbon and the other constituents, which are of course derived from the ore, fluxes, or fuels employed in the smelting operation. Of these, carbon and silicon may be regarded as being essentials, since they are always present, and without them the iron would not be pig iron, whilst the other elements present in smaller quantities in ordinary pig iron are not essential.


Pig irons vary very widely in composition and in properties. Indeed, the only points in common are the method of production and the invariable presence of carbon and silicon. Apart from these they might be considered as different metals, so much do they differ in properties.

Pig-iron is thus essentially iron containing from 2 to 4·5 per cent. of carbon, existing partly in chemical combination with the iron, and partially as mechanically-distributed uncombined or graphitic carbon, and on the relative proportion of the two forms of carbon depends the most striking difference between the varieties. When a pig-iron containing most of its carbon in the form of graphite is broken, the fracture is dark grey, or nearly black, in colour, and shows distinct flakes of graphite and is called a grey iron; on the other hand, if most of the carbon is present in combination, the fracture is silver-white in colour, granular but not largely crystalline, showing no trace of graphite, and the iron is said to be white.

In the greyest iron the carbon is almost wholly uncom-

bined, whilst in the hardest white iron it is almost entirely combined. Upon the relative proportions of the two forms of carbon, modified by the presence, mode of occurrence, and varying proportions of the foreign elements above-mentioned, depend the wide variations in the colour, hardness, strength, fusibility, specific gravity, behaviour when treated with acids, and adaptability of the metal to special purposes; but in all its varieties it differs from malleable-iron and steel by an almost total absence of ductility, in being unforgeable and unweldable; it is also more brittle, not so tough, and is usually harder than malleable-iron. The greyest iron corresponds to the largest proportion of graphitic carbon, and the larger the proportion of graphite the weaker is the metal. The graphite is distributed through the iron in the form of very thin plates, with their long axes nearly at right angles to the surfaces of cooling, so that when the pig is broken the fracture is determined along the cleavage planes of the graphite, which makes the graphite appear more prominent than its percentage would seem to warrant. White iron corresponds to the condition of the largest proportion of combined carbon. Between the two extremes, the gradation is more or less gradual, although at a certain intermediate stage the metal exhibits white iron dispersed through a matrix of grey, such metal being described as mottled pig-iron.

Pig-iron, in cooling from a state of fusion, crystallises in octahedral crystals; the dominating form of crystals being the octahedron or the cube, but crystals are difficult to obtain. The specific gravity of pig-iron varies from about 7.2 in grey to about 7.5 in white iron.

Pig-iron is usually found in commerce in the form of oblong blocks or pigs of  section, about 3 ft. long, and weighing about 1 cwt., the metal being run direct from the blast furnace into open grooves or channels of the above section, formed in the sand of the pig-bed in front of the furnace.

The various qualities of pig-iron as delivered from the blast furnace are distinguished by marks or numbers indicating the grade or quality, and the purposes to which they are applicable. The pig-iron produced from the same ores is broadly described as grey, mottled, or white iron, according

to the appearance of the fracture, but each variety is again further classified. Thus in the Cleveland, in Scotland, and in the Midlands district, according to the colour, strength, and general appearance of the fracture of a freshly broken pig, foundry pig is described as being of No. 1, No. 2, No. 3, No. 4, or No. 4 forge; whilst in Lancashire the No. 4 forge, or strong forge of the Cleveland district, is represented by V, whilst the other numbers or grades are designated by the same series of numbers in the two districts. In America Nos. 1 to 10 are used, No. 1 being the greyest, but three



Fig. 13.—Pig-iron No. 1 Fracture.

highly siliceous or silver grey irons, which are not included in the classification used in this country, are inserted between our numbers 3 and 4. In all cases No. 1 mottled and white are the same, the difference being in the arrangement of the intermediate numbers or in the introduction of other grades.

The grading is based entirely upon the appearance of the fractures when the pigs are broken. Though this method of classifying pig-irons is in general use, it is most unsatisfactory: (1) because there is no absolute standard to which each grade must conform, and (2) because the fracture may depend on other conditions beside the actual chemical composition of

the metal. At present no perfectly satisfactory substitute has been found. The following are the properties usually ascribed to the various grades.

No. 1, No. 2, and No. 3 grades of pig-iron are especially applicable to foundry purposes and for special casting;

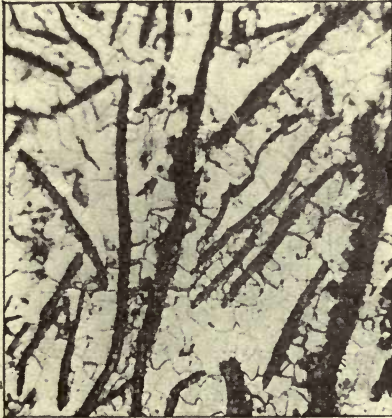


Fig. 14.—Hematite Iron No. 1 Micro Section.



Fig. 15.—Cleveland Iron No. 1 Micro Section.

No. 4 is available for foundry purposes, especially when mixed with softer irons; No. 4 Forge or V is only applicable for conversion into malleable-iron in the puddling furnace. The market value of the several grades thus decreases from No. 1 to No. 4, the higher number being the cheaper iron.

No. 1 pig-iron is the darkest grey; its fracture is largely crystalline and presents numerous graphitic planes (Fig. 13). It contains the maximum proportion of graphite, is the most readily fusible, is deficient in hardness and strength, and the pig breaks with a dull leaden sound, indicating but little



Fig. 16.—Pig-iron No. 2 Fracture.

tenacity. This metal is used for the finest and most accurate castings, where great strength is not required. The surface of the molten metal is dark and sluggish-looking, not giving off sparks and splashes, and as it cools in mass a thick scum or dross separates on its surface.

Under the microscope No. 1 iron is seen to consist of a ground mass of ferrite (in this case silicon ferrite), scattered through which are large plates of graphite and very small particles of pearlite; the latter, however, can only be made out under high magnification. If the iron is a foundry pig, and therefore contains a considerable quantity of phosphorus, the phosphide eutectic will also be seen as the portion which solidified last.

No. 2 pig-iron is lighter in colour than No. 1; usually the surface of the pig is smoother, it is finer in grain, more regular in fracture, and is a little harder and stronger than No. 1, but is not quite so fluid when in the molten state. The surface of the molten metal is of a clearer red than No. 1, and it flows from the foundlers' ladle in large sheets, splashing a little, and its surface exhibits as it cools a series of lines or figures ever varying as though the surface were in circulation, such appearances continuing until the metal becomes pasty. A scum rises to the surface of molten No. 2 pig-iron, but not to the same extent as in No. 1.



Fig. 17.—Pig-iron No. 3 Fracture.

No. 3 pig-iron is still lighter in colour, the crystals are much smaller, the fracture smoother, more compact and dense-looking; it is also much harder, stronger, and tougher than the lower numbers, and is consequently largely used in conjunction with scrap for the large castings required in structural ironwork, the usual specification test for which is that a bar, 2 in. deep by 1 in. in width, supported upon 3-ft. centres, shall not break with a less weight than 28 cwt. applied at centre; although some engineers will accept a load of 24 cwt., whilst others specify 32 cwt. as the breaking load; but this latter is extremely difficult to obtain with

ordinary hot-blast pig-iron. No. 3 pig-iron contains less graphite than No. 1 or No. 2, and has not the same fluidity when melted, whilst the molten metal throws off sparks abundantly as it is poured from the foundry ladle, and its surface is freer from scum than either of the lower numbers, but the surface-figuring spoken of with respect to No. 2 is much less distinctly seen with the metal of No. 3 grade.

No. 4 iron is stronger than those previously described; it is whiter in colour, more lustrous, has a granular, uneven, and more or less mottled appearance on fracture; it is not

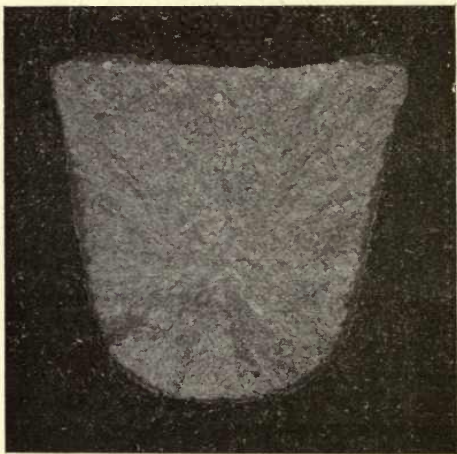


Fig. 18.—White Iron Fracture.

nearly so fluid when melted as the lower numbers, whilst the surface of the molten metal appears hotter, and the metal throws out showers of sparks as it is poured from the casting ladle. It is used only for the heaviest classes of foundry work, and is quite unsuitable for small, light, or ornamental castings.

No. 4 Forge, strong forge-pig or V, approaches to whiteness in colour, being harder and also lighter in colour than the last. This number presents a dull and more flaky appearance on fracture, and is only available for conversion into malleable or wrought-iron by the puddling process; for in

melting it passes, previous to complete fusion, through an intermediate pasty condition particularly favourable for its decarburisation in the puddling furnace, and with less loss of iron than if the metal were in a more perfectly fluid state.

White iron is hard and brittle, and breaks with a white crystalline fracture, showing no flakes of graphite. When melted it yields a pasty liquid which does not flow freely, so that it is no use for foundry work. Under the microscope it is seen to consist of portions of pearlite surrounded by a ground mass of the hard cementite.



Fig. 19.—White Iron Micro Section.

Mottled iron consists of a mass of white iron scattered through which are particles of varying size of grey iron.

Grey iron is more fluid when melted than white iron, but it requires a higher temperature for its fusion; grey iron melts at a temperature of about $1,600^{\circ}\text{C}$. or $1,700^{\circ}\text{C}$. ($2,912^{\circ}\text{F}$. to $3,452^{\circ}\text{F}$.), and white iron at a temperature of from $1,400^{\circ}\text{C}$. to $1,500^{\circ}\text{C}$. ($2,532^{\circ}\text{F}$. to $2,732^{\circ}\text{F}$.). White iron contracts in passing from the liquid to the solid state, and it passes through a soft, pasty condition before complete fusion occurs, as also through a similar condition in assuming the solid state after fusion; and these qualities adapt it for the processes of dry puddling by which it is

converted into malleable-iron, but render it unfit for foundry use. Grey iron, on the other hand, passes during fusion directly from the solid to the fluid state, and *vice versa*, and it also expands at the moment of its solidification from the fluid state, thus insinuating itself into the finest lines of the moulds in which it is contained. Hence grey pig-iron is in request, more especially for the production of light ornamental and intricate castings, so that it has thus become usual to speak of the softer grades of pig-iron as foundry pig, in

ANALYSES

Constituent.	Grey, All-mine Pig.	Bowling No. 1 Grey, Cold-blast. (Abel.)	Hematite Pig, No. 1, Grey. (Greenwood.)	Northamptonshire, Hot-blast. (Henry.)	Butterly, Hot-blast, from Derbyshire Ores.	Kirkless Hall No. 3 Pig-iron.	West Hallam, Derbyshire, No. 3 Foundry. (Whitehouse.)	North Staffordshire, Hot-blast.
Graphitic Carbon ...	3.10	2.99	3.045	1.150	3.35	3.25	2.60	2.35
Combined Carbon ...	0.04		0.704	0.554	—	—	—	—
Silicon ...	2.16	0.97	2.003	1.900	1.27	2.70	1.26	2.35
Sulphur ...	0.11	0.05	0.008	0.414	0.02	0.08	0.05	0.10
Phosphorus ...	0.63	0.50	0.037	1.807	1.09	1.73	0.72	1.10
Manganese ...	0.50	—	0.309	0.395	1.01	2.37	0.45	0.10
Metallic Iron ...	94.55	—	93.800	93.780	93.26	89.93	94.92	92.10
Calcium ...	—	—	—	—	—	—	—	—
	101.10	—	99.906	100.000	100.00	100.03	100.00	100.00

contradistinction to the harder and whiter varieties, which are described as forge qualities.

Pig- or cast-iron is decomposed when exposed to the action of sea-water, so that in time it will be left as a soft porous mass, having its original form, and being in some instances spontaneously inflammable after careful drying.

Grey cast-iron, if not too grey, is converted into white iron by sudden cooling, as in the familiar process of chill casting, where by pouring the fluid metal into metallic moulds the heat is rapidly withdrawn from the surface of the casting, which is thus converted into hard white iron, whilst the body of the casting remains grey iron; the depth and degree of the chilling or whitening depend upon the thickness, etc.,

of the mould and the character of the iron. The flat plates or pigs of Swedish pig-iron commonly present on fracture a white skin, with a grey interior, produced by the Swedish practice of running the pig metal into cast-iron open moulds. In white iron produced by the chilling of grey iron, the carbon in the chilled surface has largely remained in the combined form instead of passing into the graphitic form as in the grey metal. Molten pig-iron is a solution of various substances in liquid iron, and the form these assume in the

G-IRON.

Foundry Hot-blast. (Abel.)	Bessemer Pig, No. 2, Grey. (Greenwood.)	Grey Cinder-pig. (Noad.)	No. 4 Forge Hot-blast. (Stock.)	Mottled Charcoal Pig. (Rothorn.)	Mottled Pig.	White Pig-iron.	Spiegeleisen. (Tookey.)	Styrkan White Pig.	Jochimssthal White Pig-iron.	Cleveland No. 1. (Pattinson.)	Cleveland No. 2. (Pattinson.)
3.44	2.579 1.175	} 2.80	2.719 1.222	2.02 1.43	1.99 2.78	0.87 2.46	} 5.04	2.93	3.60	{ 2.83 0.48	2.45 0.26
1.13	1.758		1.608	0.92	0.71	1.12		0.307	0.66		1.87
0.03	0.014	0.14	0.031	0.04	trace	2.52	0.08	0.018	0.021	0.04	trace
1.24	0.038	1.66	0.016	0.04	1.23	0.91	0.16	0.021	0.52	0.30	1.00
0.43	0.130	—	0.021	2.02	—	2.72	7.57	0.724	0.531	0.57	0.93
93.73	94.304	93.55	94.309 0.074	94.08	93.29	—	86.74	96.000	95.136	93.03	94.64
—	—	—	—	—	—	—	—	—	—	—	—
100.00	99.998	100.00	100.000	100.55	100.00	—	100.00	100.000	100.468	99.56	101.15

solidified metal depends partly upon the manner of cooling, both before and after solidification ; since even after solidification, but whilst the mass is still at a red heat, it is possible to alter the nature of the metal, as by tempering, cementation, or sudden cooling.

When a mass of very grey iron is allowed to cool slowly from a state of fusion, as in the case of the molten metal standing in a foundry ladle, a scum or kish rises to the surface, which consists largely of graphitic matter ; hence fluid cast-iron is capable of holding a larger amount of carbon in solution than metal cooled more slowly from a state of fusion can retain. The scum or kish may contain as much as 0.22 per cent. of sulphur and 5.19 per cent. of manganese, the relative

proportions of these elements in the pig-iron being at the same time 0·05 and 2·62 per cent. respectively.

Hot-blast pig-iron, owing to the higher temperature of the furnace during its production, is usually more siliceous than cold-blast pig, smelted from the same or a similar mixture of ores, and from the same cause also grey pig-iron is more siliceous than white iron.

Pig-iron is soluble in acids, but leaves an insoluble residue of silicon, graphite, etc. The whole of the graphite is in the residue, but the combined carbon escapes with the evolved hydrogen.

The strength of cast-iron varies with the chemical composition, the mode of production whether by hot-blast or cold-blast, mode of treatment after leaving the blast furnace, etc.; thus cold-blast iron is stronger than hot-blast from the same ores. Annealing diminishes the strength of cast-iron; the presence of silicon beyond certain limits impairs its tensile strength, and any considerable amount of phosphorus weakens it considerably. Repeated re-melting was considered to improve the quality and strength of cast-iron, but whether this is so or not depends on the composition of the iron. Grey cast-iron is usually rendered stronger after each re-melting for a certain number of meltings, after which it becomes weaker by continued re-melting.

The tensile strength of pig-iron varies between 5 and 14 tons per sq. in. of section, but the average of good cast-iron is about 8 tons. The transverse and torsional strength of pig-iron is low, each varying between 1·5 and 4·5 ton per sq. in.; and it has an average shearing strength of 12 tons per sq. in.; whilst its crushing strength ranges from 35 to 90 tons per sq. in. of section, the average strength of good sound specimens being from 50 to 60 tons per sq. in. Owing to the high strength of cast-iron under a crushing or compressive stress, this metal is usually employed for columns, struts, etc., and but rarely in structural members subject to torsional, tensional, or transverse stresses. Cast-iron is thus stronger than wrought-iron in compression, but much weaker in tension; and within a limited range of stress it is tougher, or permits of a greater degree of deformation than wrought-iron, but its range of deformation is not large; hence it is

not so safe as wrought-iron when subject to suddenly applied stresses.

Influence of Various Constituents on Pig-iron.—Since pig-iron must owe its characters to the various constituents which are present in it, it becomes essential to study the influence of each of these separately.

Carbon is, of course, the essential constituent, and it, as pointed out in the last chapter, can exist in two forms—as graphite and as combined carbon.

Graphite is simply an intermixed constituent, and therefore can only influence the quality of the iron as any other intermixed substance would do. Graphite occurs in flakes of varying size, and as these flakes have a very perfect cleavage they have little strength, and the presence of them must necessarily weaken the iron. For this reason very grey irons are always weak. Not only is the actual amount of graphite of importance, but the size of the flakes also has an influence. A very grey iron, with large flakes of graphite, will be said to be an “open” iron, and will be weak; whilst an iron with the same percentage of graphite, but in which the flakes are much smaller, will be a “close” iron, and will be considerably stronger. The terms “open” and “close” relate to the appearance of the fracture of the pig, and depend more on the size of the graphite flakes than on the actual amount of graphite present.

Combined carbon is of much more importance. It is present as the carbide Fe_3C , always united with some of the ferrite so as to form pearlite. As the carbide is very hard and strong, its presence increases the hardness and strength of the metal. Indeed, the strength of pig largely depends on the amount of combined carbon present. Turner gives for extra soft iron, 0.08 per cent.; soft iron, 0.15 per cent.; maximum tensile strength, 0.47 per cent.; maximum transverse strength, 0.70 per cent.; maximum crushing strength, over 1.00 per cent.

Silicon is always present in pig-iron. From its similarity to carbon it was once thought that it might exist in two forms—a graphitic and a combined form—but all attempts to obtain a graphitic form of silicon have failed, and it may safely be said that silicon in iron always exists in the combined form. It is probably present as a silicide, but this dissolves in the

excess of iron, so that the presence of silicon is not detectable under the microscope; and when silicon is present the ferrite—that is, the iron ground mass, is often called silicon-ferrite.

Silicon has a two-fold influence on iron. Its direct influence is to harden the iron, but to a much less extent than carbon. Its indirect action is far more important. It has a tendency to prevent carbon remaining in the combined condition, and to throw it out in the form of graphite. Silicon, when added to iron, therefore becomes a softening agent. By its own direct action it no doubt hardens the metal, but by its indirect action of throwing the carbon out of combination it softens it far more than it hardens it directly.

Silicon thus becomes the dominating element in pig iron, the forms in which the carbon exists largely depending on the quantity of silicon which is present. It is absolutely necessary to understand this dual action of silicon, if the variations in the character of pig iron by modifications in treatment are to be understood.

The influence of silicon on pig-iron, or rather on iron containing carbon, has been investigated by Professor Turner, of Birmingham, and his classical research is the basis of all that has been done since. He found that for any important property of iron to exist in the highest degree the presence of a certain quantity of silicon was essential, the amount varying with the property under investigation.

The following table sums up the results of his work, and shows the amount of silicon necessary:—

For Maximum Hardness . . .	Under 0·80 per cent.
„ Crushing Strength . . .	About 0·80 „
„ Modulus of Elasticity . . .	„ 1·00 „
„ Density in Mass . . .	„ 1·00 „
„ Tensile Strength . . .	„ 1·80 „
„ Softness and General Working Properties . . .	„ 2·50 „
For Lowest Combined Carbon . . .	Under 5·00 „

In all cases the property under investigation fell off rapidly from the maximum as the amount of silicon was exceeded. The curves in Fig. 20 show graphically Professor Turner's results for crushing strength, tensile strength, and modulus of elasticity.

Sulphur is present in pig-iron generally to the extent of

phosphorus is to use material which contains little of that element.

Titanium frequently occurs in grey pig-iron, but in white iron it has always escaped detection, even when ores containing it have been added to the furnace charge, owing to the very high temperature required for its reduction.

Copper has been found in pig-iron from various places. Small proportions up to 0.2 per cent. of copper in pig-iron are said not to affect its quality for foundry purposes or for steel making.

Tin renders pig-iron hard and more readily fusible ; but

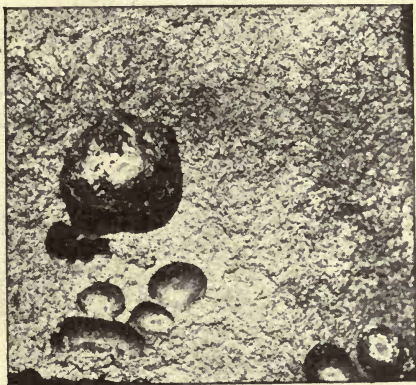


Fig. 21.—Globules of Phosphide Eutectic in Pig-iron.

stanniferous pig, after treatment in the puddling furnace, yields a malleable iron which is exceedingly cold-short and inferior in quality.

Manganese is always present in pig-iron, and if present in large quantity tends to render it white and brittle. When contained in an ore it helps to eliminate the sulphur from the resultant pig-iron. In ordinary circumstances about half the manganese in the charge passes into the iron, so that some manganese always passes into the slag. *Spiegeleisen* is a highly manganiferous pig-iron, containing from 6 to 20 or 30 per cent. of manganese, and possessing well-marked physical qualities ; thus it is very hard, and its

fracture presents large cleavage planes, which are due to fracture taking place along planes of carbide of iron.

Manganese irons containing 80 per cent. or more of manganese are now regularly made under the name of ferro-manganese; these present a granular crystalline fracture void of any cleavage or lamellar structure, and of a bronze colour.

Irons containing a large quantity of manganese can take up more carbon than ordinary pig-iron, ferro-manganese often containing up to 7 per cent. This is present either as a carbide of manganese or as a double carbide of iron and manganese. A large quantity of silicon may also be present, the alloy then being known as silicon ferro-manganese.

Grade of Pig-iron.—The grade of pig-iron, as determined by the fracture as described above depends on the appearance of the fracture, and this in its turn depends on the amount of graphite which is visible, and this again depends on the other constituents present and also the rate of cooling and other conditions.

As already remarked, silicon tends to throw the carbon into the graphitic condition, whilst sulphur has exactly the opposite effect. Other constituents have less influence, or act indirectly: manganese by tending to the removal of sulphur, and phosphorus by tending to retard solidification, help to make the iron grey. Silicon is, on the whole, the most important element in this connection, and it has been suggested that irons should be graded according to the percentage of silicon present, as determined by analysis, instead of by the appearance of the fracture. The following analyses show the sort of relationship that should exist:—

HÆMATITE PIG (C. H. RIDSDALE).

	1	2	3	Forge
Graphitic Carbon . . .	3·52	3·40	3·10	2·30
Combined " . . .	·18	·25	·36	·79
Silicon	2·85	2·60	2·08	1·35

FOREST OF DEAN HÆMATITE (PATTINSON & STEAD).

	1	2	3	4	Mottled	White
Graphitic Carbon .	3·897	3·660	3·020	2·865	2·375	·825
Combined „ .	·395	·570	1·070	1·065	1·316	2·387
Silicon	1·073	·975	·587	·728	·401	·305

These figures show the way in which the combined carbon rises as the silicon falls. It is only the combined carbon that

need be considered, since, if this be fixed, the amount of graphite will vary with percentage of total carbon. This method of grading is now being largely used, but to make it satisfactory, the amount of sulphur and manganese must also be considered, and this would make the matter much more complex.

It must be remembered that grading by the appearance of the fracture is very uncertain, and leaves far too much to the personal equation. If an iron be cooled slowly there will be more time for the carbon to separate, and the iron will tend in the direction of greyiness, whilst if the cooling be rapid, the separation of the graphite may be retarded or prevented, thus modifying the iron in the direction of whiteness. When iron is cast, as it now sometimes is, in iron, instead of in sand moulds, the outer surface becomes converted into white iron, whilst the mass of the pig is far less graphitic than it would have been if the cooling had been slower. Grading by the appearance of the fracture is therefore only of value if the iron is cast always under the same conditions.

If a white iron be kept for a considerable time at a temperature a little below its melting point, the carbon is almost completely separated.

Varieties of Pig-iron.—There are many varieties of pig-iron.

Foundry pig is iron suitable for use in the foundry. It may be of any grade, and therefore may contain varying quantities of silicon and combined carbon, but it will always contain from .7 to 1.25 per cent. of phosphorus.

Bessemer or hæmatite pig is pig-iron suitable for conversion into steel by the Bessemer or open-hearth steel processes. It must not contain more than .06 per cent. phosphorus or .05 per cent. sulphur. For the Bessemer process about 2.5 per cent. of silicon should be present, but for the open-hearth process the amount of silicon is unimportant. It is called Bessemer pig because it was made for use in the Bessemer process of making steel, and hæmatite pig because it is usually made from hæmatite ore.

Basic pig is pig iron made for the basic Bessemer or Thomas Gilchrist process of steel-making. It is, of course, not "basic" in the chemical sense. It should contain from

3 to 4 per cent. of phosphorus, and the silicon should be as low as possible, never more than 1 per cent., so that the iron is usually white.

All mine pig is pig-iron, made, in the Midlands, from iron ore without the admixture of slag or cinder from the puddling furnaces. In most districts all the pig-iron made is of this character, and the term is not used.

Cinder pig is pig-iron made from a charge consisting almost entirely of puddlers or other slag or cinder. It is usually very high in phosphorus, often spongy, and porous in texture. The term is only used in the Midlands.

Glazed pig is a pig-iron containing a large percentage of silicon, made accidentally, and so called from the bright fracture. In the United States such iron is called silvery or silver-grey iron.

A geographical classification is sometimes used, thus: Scotch pig is made in Scotland, Middlesbrough (or Cleveland) pig is made in Middlesbrough, and so on; in Scotland the pigs are further marked with the name of the works where they are made, and some works have such a high reputation that their brands of iron fetch a much higher price than others.

For instance, on May 11th, 1906, prices were :—

	s.	d.	
Cleveland No. 1 . . .	51	9	per ton.
„ No. 3 . . .	50	3	„ (F.O.B. Cleveland).
„ White . . .	48	6	„
Scotland—			
Gartsherrie No. 1 . . .	65	0	„
Coltness „ . . .	74	0	„
Summerlee „ . . .	68	6	„
Langloan „ . . .	67	6	„
Clyde „ . . .	64	6	„ (F.O.B. Glasgow).
Carnbroe „ . . .	62	0	„
Glengarnock „ . . .	66	0	„
Eglington „ . . .	60	6	„ (F.O.B. Ardrossan).
Shotts „ . . .	68	0	„ (F.O.B. Lent).
Lincolnshire No. 3 . . .	55	6	„
Derbyshire „ . . .	58	6	„
Staffordshire . . .	53	0	„
Lancashire . . .	54	0	„

It will thus be seen that the prices vary very much. No. 1 is always the most expensive, and the prices fall at about 2s. 6d. per ton for each number. Of course, the purchaser has

to consider the cost of carriage to the place where he will need to use the metal from the port or station at which it is delivered f.o.b. (free on board) at the price quoted. In the case of Cleveland iron, no particular maker's iron fetches a higher price than others, and the buyer does not usually ask for any particular make, but simply for good makers' brands (G. M. B.).

Production of Pig-iron.—The amount of pig-iron made in the world in 1905 was :—

United Kingdom	.	.	.	.	.	9,592,737 tons.
United States	.	.	.	.	.	22,992,380 „
Germany	.	.	.	.	.	10,066,553 „

Pig-iron Alloys.—A large number of alloys are now made which may be classed with pig-irons because they are made in the blast furnace by exactly the same processes and contain the same impurities. Some of these have already been mentioned.

Manganese Alloys :—

Spiegeleisen, containing up to 30 per cent. manganese.

Ferro-manganese, containing up to 85 per cent. manganese.

Silicon Alloys :—

Ferro-silicon, containing up to 15 per cent. silicon.

Silicon ferro-manganese, containing up to 70 per cent. manganese and a large quantity of silicon.

Chrome Alloys :—

Ferro-chrome, containing up to 65 per cent. of chromium.

Many other alloys are made by melting in crucibles.

CHAPTER VI.

PREPARATION OF THE ORES.

THE production of pig-iron from the various ores of iron comprises two stages—the preparation and the smelting of the iron ores.

Owing to the comparatively small value of iron, the ores are not usually submitted to any complicated or expensive mechanical treatment for the separation of the gangue or earthy portions, before calcination or smelting, except in cases where magnetic separation can be profitably used.

The preparatory treatment of the ore may include *a*, Mechanical preparation of the ores; *b*, Weathering of certain classes of ores; *c*, Roasting, or calcination of the ore; *d*, Magnetic concentration.

In England iron ore is sent to the kiln or direct to the furnace in lumps of irregular size, often mixed with a considerable amount of small material, as it is delivered at the works from the mine. At one time it was customary in the Cleveland district to break the ore into lumps approximately of from 4 in. to 6 in. cube; and in the hæmatite districts, where the furnaces were smaller, into 2-in. cubes resembling road-metalling, whilst for the still smaller furnaces employed in Sweden the pieces were only about 1-in. cube, but this sizing is not necessary for the modern large furnaces. In some districts the hard ores are broken by stone crushers, such as the “Blake,” in which the ore is broken by a strong oscillating jaw, moving to and from a corresponding hard fixed face; or in the case of calcined ores by passing between hard cast-iron rollers.

Weathering.—Weathering of iron ores is only necessary for such ores as contain much pyrites or shale; in which case, instead of directly calcining, or in exceptional cases after

calcination, the ores are exposed in heaps to the action of the atmosphere. Under the action of air and moisture, the sulphur is oxidised and produces soluble sulphates, which are dissolved out by the rain. This method is not applicable to the treatment of calcareous ores, since the soluble ferrous and cuprous sulphates formed by the oxidation would be decomposed by the lime, with the formation of a sparingly soluble calcium sulphate, which largely escapes solution; and thus the copper and sulphur would both remain in the ore, although in different states of combination from those in which they occurred in the original ores. Also such calcareous ores cannot be subjected to any prolonged weathering after calcination, otherwise the ore would break up and fall into powder, owing to the slacking of the lime during the lixiviation for the solution of the soluble sulphates, and so be unfit for introduction into the blast furnace.

Suitable ores may be weathered for three or four months; and in exceptional cases, as with the pyritous siliceous hæmatites of Germany, the weathering after roasting extends over one, two, or three years, with occasional lixiviation or washings during the whole period. Certain nodular argillaceous ironstones which are accompanied by shale suffer oxidation on exposure to the atmosphere for a short time, whereby the shale, which is not readily separated from the ore as it is first received from the mines, becomes easily separable. Again, certain spathose ores are converted by a limited exposure to the weather into brown hæmatite; but in all these special cases it becomes necessary not to carry the operation of weathering too far, otherwise the ore falls to powder and becomes unfitted for charging into the blast furnace.

Weathering is now completely abandoned except in a few outlying districts where the output is very small. The space required for the weathering of the large quantities of ore required for a modern blast furnace would alone render the process impracticable.

Calcination.—The calcination or roasting of iron-ores expels water, carbon-dioxide (CO_2), sulphur, and substances which are volatile under the influence of heat, or the combined action of heat and atmospheric air. The process leaves the ore in a more or less porous condition, more readily permeated

and acted upon by the reducing gases of the blast furnace: The partial oxidation which occurs during calcination converts the ferrous compounds—such as are contained in spathic ores, and which would readily combine with and form fusible compounds with silica in the blast furnace—into ferric oxide, which does not so readily combine with silica.

The changes produced by calcination are comparatively simple. They are partially produced by the action of the heat, and partially by the oxidising action of the air. The iron will be present in the ore, as ferric oxide (Fe_2O_3), ferric hydrate ($2\text{Fe}_2\text{O}_3, 3\text{H}_2\text{O}$), black oxide of iron (Fe_3O_4), ferrous carbonate (FeCO_3), and perhaps a small quantity of pyrites (FeS_2).

Ferric oxide will be unchanged, except that if the temperature be high it may be partially converted into the black oxide, this change taking place much more readily in the presence of reducing agents, and in some cases reduction may even go further, ferrous oxide being produced; ferric hydrate will be converted into the oxide by expulsion of water. Ferrous carbonate is decomposed, ferric oxide being left thus: $2\text{FeCO}_3 = \text{Fe}_2\text{O}_3 + \text{CO} + \text{CO}_2$, one part of the carbonate giving .69 parts of the oxide. Sometimes in the analysis of an ore ferrous carbonate is stated as FeO and CO_2 ; in that case it may be considered that the FeO is oxidised to Fe_2O_3 , thus $2\text{FeO} + \text{O} = \text{Fe}_2\text{O}_3$, and the carbon-dioxide is expelled. Each 1 part of ferrous oxide will give 1.11 parts of ferric oxide.

The pyrites is oxidised, yielding ferric oxide and gaseous sulphur dioxide: $\text{Fe}_2\text{S}_2 + 11\text{O} = \text{Fe}_2\text{O}_3 + 4\text{SO}_2$, one part of pyrites giving .67 parts of the oxide. In either case the ferric oxide may be subsequently converted into the black oxide. It will be seen, therefore, that whatever the form in which the iron exists in the ore, it will be in the condition of oxide after calcination.

Manganese will be present usually as carbonate, which will be decomposed thus: $3\text{MnCO}_3 = \text{Mn}_3\text{O}_4 + 2\text{CO}_2 + \text{CO}$, 1 part of the carbonate giving .66 of manganic oxide. This may also be written as if the carbonate were made up of MnO and CO_2 , in which case the carbon dioxide will be expelled and the manganous oxide converted into manganic

oxide : $3\text{MnO} + \text{O} = \text{Mn}_3\text{O}_4$, 1 part of manganous oxide giving 1.075 parts of manganic oxide.

Lime and other carbonates, if present, will be decomposed, the metallic oxide being left and carbon dioxide evolved thus : $\text{CaCO}_3 = \text{CaO} + \text{CO}_2$, 1 part of calcium carbonate giving .56 parts of lime. Water will, of course, be expelled, and organic matter will be partly volatilised and partly oxidised.

As a result of these changes, there will be considerable loss of weight, and the resulting calcined ore will necessarily be richer in iron than the raw material.

An example will make this clear. Assume an ore to contain :—

Ferrous Carbonate	.	.	.	.	.	60 per cent.
Manganous Carbonate	.	.	.	.	.	2 "
Calcium Carbonate	.	.	.	.	.	8 "
Silica, Alumina, etc.	.	.	.	.	.	10 "
Pyrites	.	.	.	.	.	1 "
Organic Matter	.	.	.	.	.	10 "
Water	.	.	.	.	.	9 "
						<hr/>
						100 "

Required to find :—

(1) The loss on calcination.

(2) The percentage of iron in the raw and in the calcined ore.

To find the loss on calcination, the first step will be to find what will be the weight of 100 lb. of raw ore after calcination, which can be easily obtained from the data already given.

Ferric oxide from Carbonate	.	.	60	\times	.69	$=$	41.40
" " " " "	.	.	2	\times	.66	$=$	1.32
Manganic oxide from Pyrites	.	.	1	\times	.67	$=$	.67
Lime	.	.	8	\times	.56	$=$	4.48
Silica, etc. (unchanged)	.	.	.	.	.	$=$	10.00
						<hr/>	
Weight after calcination	.	.	.	.	.		57.87

That is, 100 lb. of the raw ore will give 57.9 lb. of the calcined ore, or the loss will be 42.1 per cent.

The composition of the ore might have been written :—

Ferrous oxide	37.20
Manganous oxide	1.23
Lime	4.48
Pyrites	1.00
Carbon dioxide	27.08
Silica, etc.	10
Organic Matter	10
Water	9
	<hr/>
	99.99

Using this analysis the figures will work out :—

Ferric oxide from Carbonate . . .	$37.2 \times 1.11 = 41.3$
" " " Pyrites . . .	$1.00 \times .67 = .67$
Manganic Oxide . . .	$1.23 \times 1.07 = 1.3$

the other figures, of course, working out the same as above.

The percentage of iron in the ore can be readily obtained.

Ferrous carbonate contains	48.3	per cent.	iron.
Ferrous oxide	77.8	" "	
Ferric oxide	70.0	" "	
Pyrites	46.7	" "	

So that the percentage of iron will be $(60 \times .483) + (1 \times .467) = 29.45$, calculated from the analysis written according to the first method, and $(37.3 \times .778) + (1 \times .467) = 29.48$ if it be written by the second method.

The percentage of manganese can be similarly calculated, using the factors given on p. 248.

Since 100 parts of the raw ore give only 57.9 parts of the calcined ore, the percentage of iron will be :

$$(41.4 + .67) = \frac{42.07 \times .7 \times 100}{57.9} = 50.8 \text{ per cent.}$$

Forge- and mill-cinder, which are essentially ferrous silicates, when used as part of a blast furnace charge, is usually roasted in an oxidising atmosphere, which decomposes it, separating the iron in the form of ferric and magnetic oxides, and leaving the silica in its free condition.

The loss of weight during the process of calcination varies with different ores, for, whilst the Blackband bituminous iron-ores of Scotland lose by roasting in some cases as much as 50 per cent. of their weight, the Welsh argillaceous ores lose from 25 to 30 per cent., or an average of about 27 per

cent. The brown hæmatites lose 12 to 14 per cent., and the red hæmatites only about 6 per cent., of their weight, this loss being due to the expulsion of moisture. The loss of weight during calcination is far greater than the shrinkage of bulk, the calcined ore being left in a porous condition suitable for smelting.

The following analyses of Cleveland ore before and after calcination will give an idea of the changes produced :—

ANALYSES OF CLEVELAND STONE.

	A	B
Ferric oxide (Fe_2O_3)	2·60	66·25
Ferrous oxide (FeO)	38·06	—
Manganous oxide (MnO)	0·74	—
Manganic oxide (Mn_2O_3)	—	0·65
Alumina (Al_2O_3)	5·92	7·72
Lime (CaO)	7·77	6·46
Magnesia (MgO)	4·16	4·78
Potash (K_2O)	trace	0·02
Carbonic anhydride (CO_2)	22·00	—
Water (H_2O)	4·45	—
Silica (SiO_2)	10·36	11·87
Sulphur (S)	0·14	—
Phosphoric anhydride (P_2O_5)	1·07	1·13
Sulphuric „ (SO_3)	—	0·90
	97·27	99·78
Metallic iron (per cent.)	30·69	46·37

A.—Cleveland ore or stone, uncalcined. B.—Cleveland stone, after calcination.

The calcined ore may be either red or black. If it is free from organic matter, and the temperature is not too high, it will be red ; but if the temperature has been very high the red oxide may be converted into black oxide. This change takes place much more readily in presence of organic matter, so that calcined blackband ores are usually black in colour. If the temperature is too high the reduction may go on still further, ferrous oxide being produced ; and this may combine with the silica present, forming fusible ferrous silicates, which will soften or melt and frit the material together so that the calcined ore will be dense and non-porous, and in some cases even the lumps of ore may be cemented into a solid mass.

As the calcined ore is lighter than the uncalcined ore, calcination is usually carried out at the mine to reduce the cost of carriage.

Carbonate ores are always calcined. Brown hæmatites may be calcined or used raw, but it is always advisable to calcine them so as to expel the large amount of moisture which is present. Red and black ores are never calcined, except in the case of red ores to be treated by magnetic separation.

Iron ores are calcined in clamps or open heaps, between closed walls, or in variously designed kilns, the temperature being very carefully regulated so that the ores may not be softened, partially fused, or clotted together into compact masses which would be impervious to the ascending gases in the subsequent smelting operation. With such ores as the blackbands, containing much carbonaceous matter, the temperature should not rise sufficiently high to effect a partial reduction of the metal in the ore.

Calcination in Heaps.—This process, as carried on in South Wales, Staffordshire, etc., consists in placing upon a piece of level ground a bed of coal several inches thick, and then building up ore and fuel in alternate layers to form a pile 4 ft. or 5 ft. high. In the Hartz districts the ground layer is a bed of slag, upon which is placed a layer of iron ore, and then alternate layers of fuel and ore, until the whole forms a truncated pyramid about 9 ft. high, with a base measuring about 60 ft. square. In both the English and Continental methods, the fire is lighted at the base of the pile; and, as the process advances, any parts where the combustion is proceeding too rapidly, or where the calcination is too active, are damped down with small ore. In the Hartz the ores to be treated are calcareous, and the process has a duration of from eight to fourteen days; and for the calcination of each cubic foot of such ores about one-third of a cubic foot of small coal is consumed. Black-band ores often contain from 25 to 30 per cent. of combustible matter, and these or such others as contain much bituminous matter are usually roasted without any further addition of fuel or carbonaceous material.

Ores containing much carbonaceous matter, sulphur, or other combustible substances, are treated in longer but narrower heaps, rarely exceeding about 3 ft. in height; these

heaps do not attain to so high a temperature as the larger heaps, and thus the ore is not so liable to become fused together. This class of ore must be calcined in larger pieces than is the case with argillaceous and other ores free from combustible matter. Westphalia ores, which are less rich in carbonaceous matter, are usually treated in heaps of from 20 ft. to 30 ft. wide, from 15 ft. to 20 ft. high, and of various lengths, the period of calcination being from two to three months.

Devices for regulating the heat throughout the mass include modifying the size of the pile, as already noted; and building the larger pieces of ore so as to form draught-holes communicating with the interior of the heap, and placing around these draught-holes the smaller ore, whereby, when the pile is ignited, the direction of the flame and heat can be controlled by damping down the surface or opening out these draught-holes as required. In the Westphalian works draught-holes are formed between the sides of the pile and other passages in the interior of the pile; these passages are first filled with wood, and the pile is constructed by placing the larger lumps of ore around the exterior of the pile, so as to form an outer wall of ore, whilst the smaller ore is placed along the sides of the draught-holes, with the larger pieces more distant from the heated currents passing through these passages. Such a heap, upwards of 100 ft. long, burns for one month, the combustion being maintained through the draught-holes formed throughout the whole mass of the pile; and the progress of the calcination checked by throwing smaller ore upon any parts indicating a too rapid rise in temperature.

In pyritous ores, the pyrites often occurs in laminæ, plates or nodules, arranged along the planes of stratification of the ore, and since the gases passing through the pile are largely of a reducing character, the sulphur is not completely oxidised. In order to facilitate the elimination of sulphur from such ores by the process of oxidation, it is important that the lumps or blocks of ore should be placed with their planes of stratification vertical, the surface of such piles being covered with small ore to condense and collect the sulphur.

Calcining or roasting in heaps involves a large consumption of fuel. In the South Wales and Staffordshire districts $2\frac{1}{2}$ cwt.

of coal (2 cwt. small and $\frac{1}{2}$ cwt. large coal) are burnt per ton of ore. It is difficult to regulate the temperature throughout the pile, for whilst the ore in the interior is often clotted or partially fused (especially with spathic carbonates or pyritous ores), the other portions may be insufficiently or incompletely roasted. When much carbonaceous matters or pyrites are present, their combustion locally intensifies the heat, and so tends to clot the ore. Heap roasting is now almost entirely abandoned in Britain.

Calcination between Walls.—Clay-ironstone is thus treated in the Hartz, charcoal dust or breeze being the fuel. The walls of the pile are from 6 ft. to 12 ft. high, and built round three sides of a rectangular area, the floor sloping slightly towards the front or open side. In the walls are two rows of draught holes, each about 4 in. in diameter, the lower row being near the ground level, and the second about 3 ft. higher up. These draught-holes communicate with chimneys in the interior of the pile built up of the larger pieces of ore, the chimneys being connected with air-passages left in the base of the pile, or formed by pieces of timber, and so the circulation of air is effected. Less fuel is burnt, and the ore is more completely calcined.

Calcination in Kilns.—This process economises fuel and labour, the temperature is under better control, calcination is more uniform, and it is also continuous—as the calcined ore is withdrawn from the bottom of the kiln, fresh raw ironstone and fuel are added at the top.

In the Cleveland district, Gjers' kilns (Fig. 22) are generally used. They are circular in section, and are built of iron plates lined with 14 in. of brickwork; they are about 33 ft. high and 24 ft. in diameter at the widest part, having a capacity of about 8,000 cub. ft., holding, therefore, about 350 tons of ore and fuel; but they are sometimes constructed of larger size. A Gjers' kiln resembles a low blast furnace, with a conical lower portion tapering towards the bottom; and the whole is carried upon a cast-iron ring resting upon short cast-iron columns, so as to leave a clear space of about 30 in. between the bottom of the kiln and the ground. In the centre of the kiln and resting upon the ground is fixed a cast-iron cone with its apex upwards; this serves to direct outwards the descending roasted ore, which is then raked outwards between

the columns carrying the kiln, whilst fresh ore and small coal are constantly added at the top to replace the ore withdrawn at the bottom. Around the body of the kiln, and near the bottom, are openings usually closed by doors; these admit air, and through them bars or other tools are passed to break up the clotted ore.

In Scotland the ore is calcined in vertical circular kilns not unlike small blast furnaces in appearance. The kilns

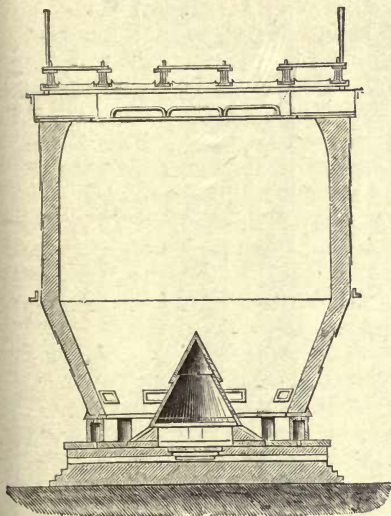


Fig. 22.—Gjers' Calcining Kiln, Vertical Section.

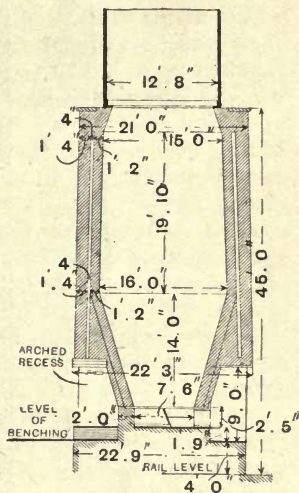


Fig. 23.—Scotch Calcining Kiln, Section.

are about 45 ft. high and 16 ft. in diameter, the charge is drawn through arches at opposite sides, it being thrown outwards by iron plates forming a triangular prism across the bottom.

With a good kiln, calcining non-bituminous ores, the consumption of fuel will be about 0·7 to 0·9 cwt. per ton of ore.

Gas Kilns.—The Swedish kiln, heated by the waste gases of the blast furnace, is of circular section, slightly conical, and about 18 ft. high, with a mean diameter of 6 ft. It is formed of an external massive structure of brick or stone,

lined with firebrick and supported by bands of wrought-iron around its circumference. The gases from the throat of the blast-furnace are conveyed to a circular main at the base of the kiln, and thence introduced by sixteen equi-distant

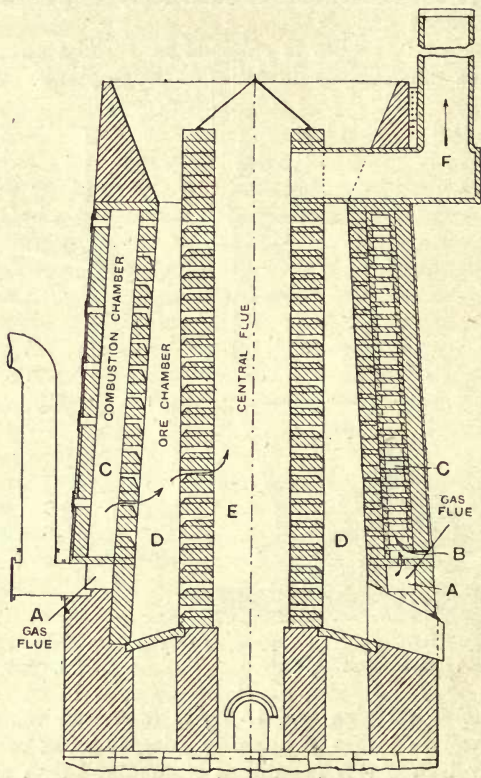


Fig. 24.—Davis-Colby Gas-fired Ore Roaster.

nozzles or jets; the air necessary to combustion is admitted a little higher up through a series of apertures controlled by dampers, and still higher is another series of openings for the introduction of the bars required to break up the charge. Numerous other horizontal openings are left in the

brickwork, for the escape of moisture and other products of calcination; at the base of the kiln are openings for the withdrawal of the charge. These kilns are capable of roasting about twenty-five tons of magnetite and schistose hæmatite in the twenty-four hours.

Where magnetic separation is to be used, it may be necessary to roast the ore in a reducing atmosphere, and for this purpose gas kilns are usually used, fired either by blast furnace or producer gas. Several forms of kiln have been devised, but the best known is the Davis-Colby, and is illustrated by Fig. 24. This consists of an annular calcining chamber *D* surrounded by a combustion chamber *C*, and surrounding a central flue *E*. The walls of the calcining chamber are perforated with a large number of openings. Gas and air are admitted to the chamber *C*, the proportions being regulated so as to give either an oxidising or reducing flame as may be required. The flame and products of combustion pass from the combustion chamber through the ore to the central flue, and thus to the chimney. The ore is supplied by hoppers at the top, and is drawn away through discharging doors at the bottom. The standard kiln is 45 ft. high and 24 ft. in diameter, and will calcine 300 tons of ore daily, with a consumption of 4 cwt. of coal for gas-production for each ton of ore calcined. Calcination is said to be very perfect, and the removal of sulphur to be complete.

Magnetic Concentration.—In various parts of the world magnetic ores occur which are contaminated by the admixture of pyrites, phosphate of iron, and other substances which reduce their value, and indeed often render them quite valueless for smelting purposes. These impurities are not magnetic, and in many cases can be separated by crushing the ore to a coarse powder and extracting the magnetic portion by means of magnets. This process is called magnetic concentration, and is now coming into use in Norway and other parts of the world. In order that magnetic concentration may be used, it is essential that the impurities to be removed be non-magnetic, and that they be present in such form that when the ore is crushed sufficiently finely the particles of magnetic and non-magnetic material will separate.

Many forms of magnetic separator have been designed, but it will be sufficient to describe one. Electro-magnets of

considerable power are almost always used, and the machine must be so arranged that the non-magnetic material does not remain entangled with the magnetic material. The power required will depend on the nature of the material to be separated—the greater its magnetic permeability, the less magnetic power will be required. Taking the magnetic permeability of pure iron as 100,000, that of magnetite is about 40,000, whilst red hæmatite is about 700, and limonite about 300. If the magnets be sufficiently powerful, hæmatite can be separated from a non-magnetic gangue, but its magnetic

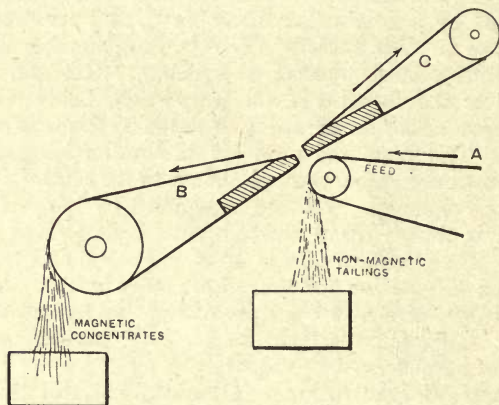


Fig. 25.—Wetherill Magnetic Concentrating Machine (Diagram).

permeability is so low that it is usually best to convert it into magnetic oxide. In the Wetherill machine, which may be taken as a type, the arrangement of which is shown diagrammatically in Fig. 25, two magnets, which may be either permanent magnets or electro-magnets, are used. These are bevelled at the edges, and the material to be treated is brought up on an endless belt which runs under one of the magnets. As the belt runs under or near the magnet the non-magnetic material falls off, whilst the magnetic material is attracted to another belt and carried to a separate receiver. The magnets may be vertical or inclined. In the form of machine shown in the sketch the ore is fed by the belt A, and the magnets are sufficiently powerful to draw the magnetic portions

over on to the belt B. The strength of current for the magnets and the speed must be determined for each ore. This machine has been used for the separation of franklenite and other slightly magnetic minerals, and by using a set of machines of varying strength, minerals of different degrees of magnetic permeability may be separated one from the other.

Most iron ores can be worked on machines of low power by first converting the iron into magnetic oxide either by heating or, better, by heating in a reducing atmosphere in a Davis-Colby or similar kiln, before crushing. Such ores as clayband and blackband ores cannot be successfully treated, as, however finely they may be powdered, they do not separate into the different constituents.

Magnetic concentration is at present chiefly used for treating poor and impure magnetites and hæmatites and such ores as franklinite.

Briquetting.—In order that magnetic concentration may be applied, the ore must be in a powder, and a powder is quite unsuitable for treatment in the blast furnace. It must, therefore, be made into blocks or briquettes which can be smelted. Large quantities of fine ore are now imported, and similar materials accumulate at many mines. These also are now frequently briquetted.

The ore for briquetting must be in the condition of a coarse powder. Magnetically separated ores are, of course, in that condition, whilst ores containing a large amount of smalls are screened to separate any pieces that are large enough for direct smelting, and the remainder is crushed to uniform size.

If the ore is at all argillaceous it will bind; if not, some binding material is added—lime, some organic binding material such as pitch, or a small percentage of a good clay. The whole is thoroughly mixed in a mill or pan with sufficient water to make a stiff paste, and this is moulded into blocks, usually by hydraulic pressure. The blocks are dried, and then heated to redness or fired in a kiln. The briquettes may be of any convenient size, but are usually about 8 in. by 7 in. by 6 in., weighing about 35 lb. They must not be so large that they cannot be conveniently handled, and they must be strong enough to resist handling. It is quite obvious

that briquetting will add to the cost of the material, and the addition of binding material will reduce the percentage of iron. Purple ore—that is, burnt pyrites from which the copper has been extracted—is now largely made into briquettes for smelting, the alkaline salts present acting as a binding material.

The following analysis of Dunderland ore and of a briquette made from it may be of interest :—

	ORE.	BRIQUETTE.
Iron	49·350	68·550
Manganese oxide	1·116	—
Titanium oxide	·110	—
Alumina	·350	—
Lime	5·050	·450
Magnesia	·378	·144
Silica	16·300	2·300
Sulphur	·025	·030
Phosphoric Acid	·415	—
Phosphorus	—	·016
Carbonic Acid	5·700	—
Water	·450	—
Organic Matter	·200	1·900

In this case the binding material was organic matter.

CHAPTER VII.

CHANGES IN THE BLAST FURNACE.

THE blast furnace in which the iron ore is reduced is a vertical stack of masonry cased with iron. The charge of solid material ore fuel and flux is introduced at the top and air is blown in at the bottom whilst the products of combustion escape at the top. The solid contents are melted and are tapped out through holes provided at the bottom of the furnace, and nothing can leave the furnace unless it be in the gaseous or liquid condition.

Chemical Changes.—Pig-iron is produced on a large scale from the ores which have been already described, and whatever may be the condition of the iron in the ore, it is always as oxide that it enters the furnace. The chemical reactions which occur in the smelting of iron are very simple, involving only the reduction of ferric oxide by carbon or carbonic oxide; but the product obtained by the reduction is a sponge of malleable-iron, enclosing the refractory gangue or earthy matters accompanying the ore, and this spongy iron is infusible. To produce pig-iron the reduced iron must be combined in the blast furnace with a proportion of carbon and silicon, whereby the metal becomes more fusible, and so separable by fusion from the gangue accompanying the ore. To prevent the loss of iron arising from the formation of rich ferrous silicates by unreduced oxide of iron combining with the silica present, a flux is added to the charge to combine with the siliceous matters of the ore, and thus prevents the formation of iron silicates (which are only reducible with difficulty), and leave the ferric oxide in a state to be readily reduced by the carbonic oxide in the furnace, or by the carbon of the fuel. Thus to extract the whole of the iron, a temperature above redness must be employed, and a flux must be added to form a fusible slag with the gangue of the ore.

The gangue accompanying iron-ores is usually either of a siliceous or of an argillaceous character, and is infusible

at the highest temperature of the blast furnace ; but by the addition of lime to the charge comparatively fusible silicates of lime and alumina are produced. At the high temperature necessarily maintained in the blast furnace, the reduced iron combines with an amount of carbon derived from the incandescent fuel in the furnace, or from the finely-divided carbon with which the mass of ore in the furnace is impregnated, and pig-iron results.

When the blast-furnace is in regular work ("in blast"), it must be kept filled to the top or throat with the mixture of fuel, ore, and flux, fresh materials being added to the top as the charge sinks down. At the same time, the blast entering through the tuyeres near the bottom of the furnace is constantly and uninterruptedly supplied, except when tapping the furnace, or (sometimes) when opening the furnace top to introduce the charge. The blast should be delivered at sufficiently high pressure to pass freely through the whole charge, and for this a pressure of from 3 lb. to 12 lb. per sq. in. in furnaces employing coke as the fuel, or from $1\frac{1}{2}$ lb. to 2 lb. per sq. in. in those consuming charcoal, is required according to the size of the furnace.

Reduction of Oxide.—The action of the blast furnace begins immediately the blast from the tuyeres meets the incandescent fuel (coke or charcoal). The oxygen of the blast is consumed within a small distance of the tuyeres, carbon-monoxide being produced and a large amount of heat evolved. The temperature is so high that no carbon-dioxide is produced, and if it were it would be at once decomposed. The gas which ascends the furnace consists, therefore, of a mixture of carbon monoxide and nitrogen from the air. As air contains 21 per cent. by volume of oxygen, and as carbon-monoxide occupies just twice the volume of the oxygen which it contains, the ascending gas will contain 79 parts of nitrogen to 42 parts of carbon-monoxide, or 65·3 per cent. nitrogen and 34·7 per cent. of carbon-monoxide, together with a small quantity of hydrogen from the decomposition of water in the blast. The carbon-monoxide is the principal and active reducing agent of the blast furnace, and it ascends along with the heated nitrogen introduced with the blast of air, together with smaller quantities of other gases, such as hydrogen, etc., it gradually

cools and imparts its heat to the descending charge. The ore is in a porous condition from its previous calcination, or from being heated in the upper portions of the furnace, and is thus in a state highly favourable to its permeation by the current of ascending reducing gases, and therefore to the reduction of the iron. The reduction of the iron is mainly effected by the carbon-monoxide, which is converted thereby into carbon-dioxide. Thus $\text{Fe}_2\text{O}_3 + 3\text{CO} = 3\text{CO}_2 + 2\text{Fe}$, whilst possibly a small proportion of the iron may also be reduced from the ferric oxide (Fe_2O_3) by the direct action of carbon, at the high temperature of the furnace. The nitrogen and other gases which do not act as reducing agents assist by their sensible heat to raise the temperature of the materials in the upper part of the furnace; and hence the higher the furnace the more perfectly is the heat absorbed from the ascending gaseous current, with a corresponding decrease in the temperature of the gases escaping from the top of the furnace, although the escaping gases from both the high and the low furnaces may contain the same percentage of combustible gas, and yield as much heat upon their subsequent combustion.

As the reduction of the iron by carbon-monoxide begins at a temperature below that at which carbon-dioxide is decomposed by carbon, the carbon-dioxide formed escapes in the waste gas. The whole of the oxide of iron should be reduced by carbon-monoxide before the temperature is high enough for the carbon to decompose the carbon-dioxide; that is, about a red-heat. Any oxide of iron which is not so reduced will either be reduced by the solid carbon of the fuel or, if by carbon-monoxide, the carbon-dioxide formed will be decomposed, in either case causing a loss of carbon by oxidising it near the top of the furnace, where it is not required, instead of at the tuyeres. When all the iron is being reduced by carbon-monoxide, the ratio of carbon-dioxide to carbon-monoxide in the waste gas (by volume) will be about 1 : 2. As the gas contains a large percentage of carbon-monoxide it is always combustible.

The limestone added to a flux is decomposed at a red heat, and the carbon-dioxide evolved is decomposed by the hot carbon, and therefore leaves the furnace as carbon-monoxide and consumes a small quantity of carbon.

The reduction of the iron is probably not quite so simple,

but probably takes place in stages as the temperature rises, lower oxides being formed as intermediate products.

Carburisation of the Iron.—The iron thus reduced is accompanied in its descent towards the furnace hearth by the earthy matters of the ore, and lime from the limestone added as flux, and during the descent of the iron it is further carburised by contact with the heated carbon, or by the decomposition of carbonic oxide with separation of free carbon, thus $2\text{CO} = \text{C} + \text{CO}_2$, an action which takes place readily in high temperatures in presence of free iron. Then the fusible compound of iron with carbon and other impurities constituting pig-iron sinks down and collects in the hearth of the furnace, above which, in virtue of its lower specific gravity, floats the fusible slag, which is formed when the earthy constituents of the ore and the lime from the flux are heated to a high temperature, and which protects the metal in the hearth from the decarburising influence of the blast which enters above it.

Reduction of Other Constituents.—The whole of the phosphorus, whether derived from the ore, fuel, or fluxes, finds its way into the pig-iron produced in the blast furnace, so that the only way to obtain an iron free from phosphorus is to use phosphorus free materials. The reduction of the phosphorus is probably due to the presence of silica.

Manganese occurring in the iron-ores will be found partly in the resulting pig-iron and partly in the blast furnace slag, as a rule about one half going into the iron and the remainder into the slag.

The sulphur in the ore is largely expelled during calcination, but such as enters the blast furnace is found along with that in the fuel or fluxes, either in the resulting pig-iron or in the slags, according as the slag is calcareous or siliceous in character. When lime is in excess in the furnace, the sulphur tends to pass into the slag as calcium sulphide, especially if the temperature be high; but if the temperature be low, iron sulphide is more stable and tends to pass into the iron. Hence, white iron, which is produced at a lower temperature than grey iron, is usually more sulphurous than grey iron, so that a high temperature with a liberal use of lime are the conditions favourable to the make of grey pig and the elimination of sulphur from the iron, whilst a proportionately larger

percentage of sulphur will occur in the slag than is found with the lower temperature accompanying the make of white iron. The larger proportion of the sulphur always goes into the slag, a comparatively small quantity going into the iron.

A comparatively high temperature is necessary to reduce silicon, and the higher the temperature of the furnace the richer in silicon is the resulting pig-iron likely to be ; thus the higher grades (*i.e.* lower numbers) of iron, which are always produced at higher temperatures, are more siliceous than the lower grades. Too high a temperature and not enough lime will sometimes produce a metal having a finely crystalline fracture and a bright lustre ; such pig is known as glazed or glazy pig, and it contains a high percentage of silica. Such pig is almost worthless either for foundry or forge use, and the remedy for a furnace producing such metal is either to lower the temperature of the blast, which is the most convenient method, or to attain the same end by increasing the burden of the furnace, and at the same time it increases the amount of lime in the charge. Such irons are made for special purposes, and are then known as silicon irons.

Manganese is always partially reduced, in general about one-half passing into the iron. The conditions which favour the reduction of manganese are a high temperature and a basic slag, since if the slag is siliceous it will tend to carry a large percentage of manganese.

Ferromanganese requires for its production a blast of the highest possible temperature that can be produced in fire-brick stoves, while the consumption of fuel is exceedingly high, amounting to about $3\frac{1}{2}$ tons of coke per ton of metal (80 per cent. manganese) ; a furnace that could yield from 50 to 60 tons of ordinary pig-iron per day yields only 12 to 20 tons of ferromanganese per day. Of the manganese present in the furnace charge, from 60 to 70 per cent. only is reduced and passes into the ferromanganese, while the remainder passes largely into the slag, but a portion also is most probably volatilised at the high temperature employed.

Chromium is very difficult to reduce, a very high temperature being required, so that each ton of ferro-chrome will require the consumption of three or four tons of coke. The whole of the chromium should be reduced or the slags will be thick and viscid. As this is not always possible, fluor spar or

Temperature and Zones of Blast Furnace.—The changes which take place in the blast furnace are, of course, largely determined by the temperature of the furnace. The temperature is highest at the zone of combustion just opposite the tuyeres, and the ascending gases are cooled by the descending charge, so that the temperature at the top of the furnace will not be visibly red, usually about 300° C. or thereabouts. The reduction of oxide of iron by carbon monoxide begins at about 300° C. and becomes much more rapid as the temperature rises, so that the conditions at the top of the furnace

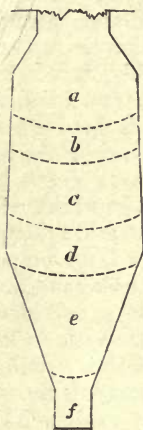


Fig. 27.—Zones of Action in the Blast Furnace Indicated by Diagram.

are very favourable for reduction, carbon monoxide being in large excess.

In the zone *a* (Fig. 27) at the top of the furnace the new charge is in course of being heated by the ascending gases, and within 20 ft. from the throat the charge has attained to a dull red heat, and the whole of its iron is reduced by carbonic oxide, with the production of a spongy metallic mass. This is the upper zone of reduction. Here also moisture will be expelled, and if coal is being used as fuel, gas and volatile matter will also be expelled. In the zone *b* the furnace is at a red heat, and the carbon-dioxide is being expelled

from the limestone, and coming in contact with the hot carbon will be reduced to carbon-monoxide; at *c* there is a full red heat, and the spongy metal begins to combine with carbon, either from that which has been deposited by decomposition of carbon-monoxide, or partly from the incandescent fuel, etc. This absorption of carbon continues through the next zone *d*, which is at a bright red heat, and where it is probable also that the reduction of sulphur, silicon, phosphorus, etc., of the charge, and its combination with the iron, is effected; at *e*—the bosh of the furnace—the temperature has reached full whiteness, and is sufficient to effect the combination and fusion of the slag-producing materials; whilst in the lowest zone *f*, or hearth of the furnace, the slags are thoroughly fused, and separate accordingly from the pig-iron; the iron sinks, and collects as the lowest layer on the bottom of the furnace, where it is protected from the action of the blast by the layer of fluid slag above it.

The production from a given blast furnace is not perfectly under control, but generally white iron is produced when the furnace is worked at a low temperature, and with heavy burdens—that is, with a large proportion of ore to fuel, and a fusible slag, as under these conditions the quantity of silicon reduced is small, whilst a considerable amount of sulphur may pass into the iron. With an increased temperature and lighter burdens the pig-iron is usually grey and more siliceous. Hence, to obtain an increased make from the same materials whilst maintaining the quality of the pig-iron, the other conditions of ore and charging remaining the same, it is necessary to enlarge the furnace. If the make be increased by heavier burdening, other conditions remaining the same, the quality of the pig-iron is deteriorated, often turning the make into white iron, with the production at the same time of a scouring slag containing ferrous silicate. The nature and quality of the slag produced in the furnace varies with the quality of the metal produced.

Blast Furnace Slags.—The gangue or earthy matters of the ore, consisting chiefly of quartz (silica), clay (aluminous silicates), or of calcium carbonate, together with the earthy matters or ash of the fuel, are separately quite infusible or fusible only with difficulty; and therefore it is necessary to add some substance (flux) capable of combining with them

to produce readily fusible compounds or slags. As the gangue to be fluxed away is usually silica, or clay (a silicate of alumina), and by the addition of lime, fusible silicates of lime or lime and alumina can be produced, lime being added for convenience in the form of limestone, a carbonate. To reduce the amount of limestone needed different iron ores often are mixed together, the gangue of the one acting as a flux to the other. For instance, by the judicious mixing of siliceous and calcareous hæmatites, or by the addition of argillaceous ores to such a mixture, the necessary slag is produced, without the addition of a large amount of limestone. Some of the red hæmatites of Sweden, etc., contain sufficient calcareous matter to act as the flux; they are accordingly very economical in fuel, and are known as "self-going" or "self-fluxing" ores.

The nature and quantity of the flux depends accordingly upon the character and composition of the gangue accompanying the ore; for a gangue containing silica clay or similar material limestone is the flux always employed. Without a flux the silica alone is infusible, but would at the hottest zone of the furnace combine with ferrous oxide from the ore to produce a fusible ferrous silicate, the iron in which would escape reduction. When limestone is added, it becomes converted by the heat into caustic lime, and then combines with the silica and alumina of the ore, producing a fusible double silicate of lime and alumina, to the practical exclusion of iron from the slag. For ore having a quartzose or siliceous gangue, such as the hæmatite ores of Lancashire, Cumberland, etc., both lime and argillaceous matters are often added, the last mentioned often in the form of an iron-ore (such as Antrim) which contains alumina. Bauxite, a mineral containing about 57 per cent. of alumina and 25 per cent. of ferric oxide, is another flux sometimes used for siliceous ores. With the very high temperature now used in blast furnace working, the slags are essentially silicates of lime, the quantity of alumina being small except when clay ironstones or argillaceous ores are being smelted, and argillaceous fluxes are little used except in districts where small furnaces are in use.

Highly fossiliferous limestones contain much earthy phosphates and pyrites, and so are to be avoided as fluxes; and dolomites (magnesian limestone) are also undesirable,

since magnesia decidedly diminishes the fusibility of blast furnace slags.

The use of caustic lime instead of raw limestone has been suggested, but it is rarely employed. The lime is considerably lighter than the limestone, but it is powdery and troublesome to handle. Probably it absorbs carbon dioxide at the top of the furnace, thus being converted into carbonate, which is decomposed again as the temperature rises. There is, therefore, no saving of heat. In rare cases the limestone is added to the kiln and calcined with the ore, but this does not seem to be any advantage.

ANALYSES OF BLAST FURNACE SLAGS.

	A	B	C	D	E	F	G	H
Silica . . .	38.48	43.07	39.52	36.50	31.46	29.00	27.68	42.96
Alumina . .	15.13	14.85	15.11	22.59	8.50	19.00	22.28	20.20
Lime . . .	32.82	28.92	32.52	32.68	52.00	40.00	40.12	10.19
Ferrous oxide	0.76	2.53	2.02	0.06	0.79	—	0.80	19.80
Manganous oxide . .	1.62	1.37	2.89	0.32	2.38	—	0.20	1.53
Magnesia . .	7.44	5.87	3.49	5.83	1.38	8.5	7.27	2.90
Calcic slphd.	2.22	1.90	2.15	—	2.96	5.5	2.00	1.32
Sulphur . .	—	—	—	1.74	—	—	—	—
Alkalies . .	1.92	1.84	1.06	0.96	—	—	—	1.10
Phosphoric anhydride	0.15	—	—	—	—	—	—	—
	100.54	100.35	98.76	100.68	99.4	100.00	100.35	100.00

A.—From Dowlais making grey iron (Riley). B.—From Dowlais making white iron (Riley). C.—Cold blast furnace working with coke (Percy). D.—Cleveland slag. E.—Producing grey Bessemer iron slag, disintegrates in air. F.—Scotch slag. G.—From Cleveland ores (Bell). H.—Scouring cinder, South Wales pig (Nord).

Slags from the blast furnace differ in physical character according to the nature of the ore and the fuel; to the quality of the pig-iron being produced; and also as the burden of the furnace varies from light to heavy. Blast furnace slags are usually double silicates of lime and alumina, of the composition represented by the formula $2RO, SiO_2$ where R is usually partly lime and partly alumina, the lime almost always being in large excess. A typical formula $3(2CaO, SiO_2) + 2Al_2O_3, 3SiO_2$, in which the two bases are in equivalent

proportions, is often given, but is rarely met with in practice. More siliceous slag is often produced by charcoal furnaces. The lime is always more or less replaced by magnesia (MgO), manganous oxide (MnO), and in the case of "scouring cinder" by ferrous oxide, whilst the silica also sometimes may be replaced to a small extent by alumina; the slags often contain a small quantity of potash and soda. Slags containing the larger proportion of manganous oxide, or of lime, frequently contain also a larger proportion of sulphur.

The colour of blast furnace slags varies from white or grey, through varying shades of brown, yellow, green, and blue, to black. Generally a white or grey slag is indicative of a furnace producing grey iron, and working upon a light burden; whilst dark-coloured or black slags result when the furnace is making white iron and working upon a heavy burden or a highly siliceous iron with a very siliceous slag; but the colours of the slags are also influenced by the bases present. Metallic oxides give the slags their distinctive tints; for instance, the presence of small proportions of manganous oxide in the slag produced during the smelting of manganiferous hæmatites gives an amethyst tint, which, however, is not apparent when the slag is vesicular or pumice-like in structure. Manganous sulphide also imparts a yellow or brownish-green colour to the slag, and the presence of excessive proportions of alumina manifests itself in the production of an opalescent slag, such as is frequently observed in Staffordshire from furnaces smelting clay iron-stone. Lime, when in considerable proportions, is indicated by a dull, stony fracture of the slag, and if it becomes excessive, —i.e. more than that required for the formula $2\text{CaO}, \text{SiO}_2$; free lime separates as the slag solidifies, and therefore on exposure to a damp atmosphere it disintegrates and falls to powder; such slags, when ground and mixed with about one-fourth of their weight of caustic lime, yield a good cement or mortar for building purposes. Slags containing a large proportion of lime also take up a considerable quantity of the sulphur present in the fuel and in the ore, with the production of calcium sulphide, the presence of which is evidenced by the evolution when the slag is quenched with water of the characteristic odour of sulphuretted hydrogen (H_2S), or of sulphurous anhydride (SO_2) if the slag be

not so far cooled as to prevent the escaping gas (H_2S) from taking fire on coming into contact with the atmosphere. A similar liberation of sulphuretted hydrogen occurs when barium or manganous sulphide is present in the slag which is treated with water.

The appearance of the slag depends largely on the molecular condition induced by the varying rapidity or method of its cooling. Thus a slag which has been cooled quickly will be vitreous and have conchoidal fracture, and be more or less translucent on the thinner sections, whilst if a similar slag be cooled more slowly it will show on fracture dull, stony, and opaque, and the same slag if allowed to flow over damp sand or through water will become changed to a vesicular, brittle, friable, and pumice-like mass, from the action of the steam passing through it.

The fusibility and fluidity of the slag also to some extent indicate the working of a furnace; under the same general conditions a refractory slag means grey iron, and a very fusible slag white iron. Slags which flow in continuous, steady, but more or less viscous streams, passing slowly from the liquid to the solid state, are often produced when a furnace is working upon light burdens, and have generally a grey or whitish colour; whilst heavy burdens and a reduced temperature of the furnace are accompanied by a scouring slag or cinder, flowing as freely as water, and readily solidifying without passing through the viscous condition. These scouring slags are often also of a dark-green or greenish-black colour from the presence of ferrous oxide.

Thermal Phenomena of the Blast Furnace.—The heat which is supplied to the blast furnace is used in various ways, and it is of great importance to know what becomes of the heat so as to be able to judge the economy with which the furnace works.

Heat is supplied by the combustion of the fuel, and by the heat carried in by the blast, which is now always used hot, and the heat is either utilised in producing chemical changes within the furnace, carried off with the products from the furnace, or lost by oxidation or otherwise.

Sir Lowthian Bell, from a series of experiments, made out an estimate of the amount of heat required to work a blast furnace under the ordinary Middlesbrough conditions, and

this estimate will give a very good idea of the way in which the heat is utilised. It is calculated for 20 parts (lb. or otherwise) of iron obtained, the heat units used being the 1 lb. Centigrade units—that is, the amount of heat required to raise 1 lb. of water 1° C. Notes are attached explaining the meaning of each item.

	LB.		HEAT UNITS.
(1) Evaporation of water in coke	·58 ×	540 =	313
(2) Reduction of 18·6 lb. of iron from Fe_2O_3	18·6 ×	1,780 =	33,108
(3) Carbon impregnation	·6 ×	2,240 =	1,440
(4) Expulsion of CO_2 from limestone	11 ×	370 =	4,070
(5) Decomposition of CO_2 from limestone	1·32 ×	3,200 =	4,224
(6) Decomposition of water in blast	·05 ×	34,000 =	1,700
(7) Reduction of phosphoric acid, silica, etc.			3,500
(8) Fusion of Pig	20 ×	330 =	6,600
(9) Fusion of Slag			15,356
Heat usefully used			<hr/> 70,311
(10) Transmission through walls of furnace		3,600	
(11) Carried off in tuyere water		1,800	
(12) Expansion of blast and escape into foundations		3,389	
		<hr/>	8,789
(13) Carried off in gas			7,900
			<hr/> 87,000

The heat is obtained mainly by the combustion of the coke. If carbon be burned to carbon dioxide, it will evolve 8,000 units of heat, but if it be burned to carbon monoxide it will evolve only 2,400 units of heat. At the tuyeres it is burnt to carbon monoxide only, but other oxidations—mainly reduction of the oxide of iron—go on higher up the furnace, so that the gas which leaves the furnace contains about one-third of its carbon in the form of carbon dioxide and two-thirds as carbon monoxide. The average heating value of a pound of carbon so burnt will obviously be :—

$$\frac{(1 \times 8,000) + (2 \times 2,400)}{3} = 4,266$$

The coke which is consumed may be taken as containing 90 per cent. of carbon, so that the average heating value of 1 lb. of coke will be $4,266 \times .9 = 3,840$ units. The heat carried in by the blast at 540° C. may be taken as being 12,000 units

for each 20 lb. of iron, so that $87,000 - 12,000 = 75,000$ will be the amount of heat to be supplied by the fuel, and to supply

this $\frac{75,000}{3,840} = 19.53$ lb. of coke will be required.

The figures will, of course, vary with the conditions of working, but those given above apply to the special case.

Notes on Items of Heat Absorption.

(1) Roughly speaking, 20 lb. of coke will be required for 20 lb. of iron produced, so that .58 lb. of water would be 2.9 per cent.—a very low estimate; 540 is the latent heat of steam.

(2) Pig iron is not pure. Here it is assumed to contain 93 per cent. of iron, so that the 20 lb. of pig iron would only contain 18.6 lb. of pure iron. The reaction, $\text{Fe}_2\text{O}_3 + 3\text{CO} = 2\text{Fe} + 3\text{CO}_2$, is obviously made up of two portions: the decomposition of Fe_2O_3 , which absorbs heat, and the oxidation of CO to CO_2 , which evolves heat. Account is taken of the latter in the heat evolved by the combustion of the fuel, so that it is only the heat absorbed that is taken into account here.

(3) It is assumed that the carbon is obtained by the decomposition of carbon-monoxide: $2\text{CO} = \text{C} + \text{CO}_2$. The formation of carbon-dioxide, of course, evolves heat, but this is taken into account as before with the fuel.

(4) The limestone is split up into CaO and CO_2 . It is assumed that 55 lb. of limestone is added for each 100 lb. of iron obtained.

(5) The 11 lb. of limestone added for each 20 lb. of iron will contain 1.32 lb. of carbon as carbon-dioxide, the reduction of this to carbon-monoxide, $\text{CO}_2 + \text{C} = 2\text{CO}$, will absorb 3,200 units of heat for each pound of carbon. The formation of the carbon-monoxide will, of course, evolve some heat; but this is accounted for by the combustion of the fuel.

(6) The air is never free from moisture. Assuming it to contain .05 lb. of hydrogen for each 20 lb. of iron, the heat absorbed by the decomposition of the water, $\text{H}_2\text{O} + \text{C} = 2\text{H} + \text{CO}$, will be that given in the table. Here, again, the formation of carbon-monoxide will evolve some heat, but as

the carbon comes from the fuel this will be accounted for in the heat of combustion of the fuel.

(7) Reduction of minor constituents will absorb heat. The actual amount could be calculated if the amount of each constituent was given.

(8) Fusion of pig iron.—The latent heat of fusion of pig-iron, together with the heat required to raise it to the melting point, is taken as 330.

(9) The latent heat of slag used is not given.

(10) Can only be roughly estimated.

(11) The water used to cool the tuyeres becomes warmed and carries away heat.

(12) Can only be roughly estimated.

(13) The gas consists of carbon monoxide and hydrogen from the fuel, carbon monoxide from the carbon dioxide of the limestone, carbon dioxide from the reduction of the oxide of iron, and water vapour from moisture in the charge. The amounts of these could be calculated if data were given.

Efficiency of the Blast Furnace.—The blast furnace is a very efficient machine. Of the heat carried into the furnace—say, 87,000 units—no less than 70,311, or about 81 per cent., is usefully used; that is, used in producing reactions that are necessary to the working of the furnace; and the remainder is carried away in such ways as cannot be considerably reduced.

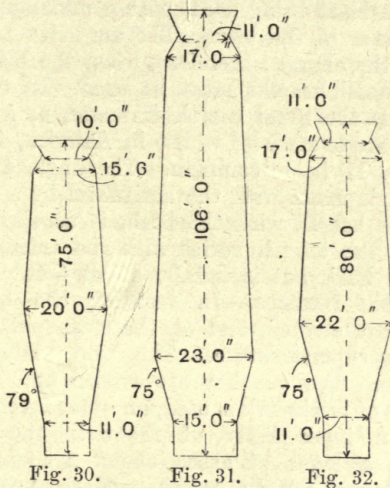
If the 19.53 lb. of fuel were completely burnt to carbon dioxide it would evolve 156,000 units of heat instead of 75,000, so that the difference (81,000 units) can be obtained by the combustion of the gas evolved from the blast furnace.

CHAPTER VIII.

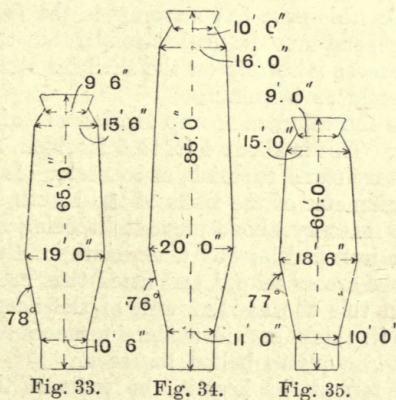
THE BLAST FURNACE AND ITS ACCESSORIES.

The Modern Blast Furnace.—The modern blast furnace used for smelting iron ore, as seen from outside, is a cylindrical or slightly conical structure of iron, carried on iron columns provided at the top, with an overhanging gallery, and the lower portion with pipes supplying air and water (see Fig. 28). Fig. 29 is a section showing the furnace when empty. It consists of a casing of iron or steel plate, lined inside with bricks to a thickness of about 3 ft.

The furnace has its greatest diameter at about one-third its height, and narrows both upwards and downwards. The opening at the top or throat is about two-thirds the greatest diameter, and the furnace may either narrow uniformly to that; the upper portion being the frustum of a cone, or it may slope much less, and be quickly contracted near the top. This upper portion of the furnace is called the shaft. From its widest part, the furnace narrows more rapidly downwards to about half the greatest diameter, and this portion, which is in the form of an inverted cone, is called the bosh, which name is also given to the greatest diameter. Below the bosh there is a cylindrical portion or hearth, in which the molten material accumulates. The furnace is thus divided into three portions, which correspond roughly to the changes which take place. In the upper portion the charge is heating up and the various reactions are taking place, in the middle portion the charge is melting and therefore diminishing in volume, and in the lowest portion the melted material accumulates. The contour of the furnace may vary very much. There may be sharp lines of demarcation between the separate parts, or they may be curved gradually one into the other. Half a dozen typical shapes are shown by Figs. 30 to 35.



Figs. 30 to 32.—Blast Furnaces.



Figs. 33 to 35.—Blast Furnaces.

pressure of the blast being used, with a maximum of about half the diameter of the bosh. The air must penetrate to the centre of the charge; therefore, when the blast pressure used is low, small hearths must be used. In this country 8 ft. or 9 ft. is the usual hearth diameter, or a little more if the tuyeres are overhung; whilst in America, for a heavy blast pressure, 11 ft. is common. The angle of the bosh, that is the angle made with the horizontal by a line joining the top of the hearth with the bosh, is usually about 75° . The depth of the hearth varies with the amount of metal which it is to hold, but is usually about 6 ft.

Building the Furnace.—In building the furnace, the iron columns are erected, and on these are put lintel plates to carry the superstructure. The iron plates are then put on, and are lined as they are carried up. Sometimes a double layer of brickwork is used, an outer layer of ordinary brick and an inner layer of firebrick, the two being separated by a layer of ashes about 2 inches thick to allow for expansion. In many modern furnaces, however, the whole lining is of firebrick. The bricks should be refractory and not too siliceous. They are always specially made to suit the curvature of the furnace, and are set in fireclay. Holes are left in the casing so as to allow of the escape of steam as the brickwork dries. Sometimes, in place of the iron casing the furnace is banded or crinolined with iron hoops. In this case the masonry is the essential part of the structure, and must be made stronger, but the tendency in modern furnaces is to rely on the shell for strength, using the bricks merely as a lining.

As soon as the columns are up the bottom of the hearth can be put in. This is about 4 ft. to 6 ft. thick, made either of very refractory stone, firebrick, or concrete. It is extended to the outer diameter of the walls of the hearth, so that the weight of the masonry above prevents it being lifted bodily should molten iron find its way underneath, and the separate stones or bricks are so shaped and fitted that no portion can be lifted. On this the circular wall of the hearth is built. It is about 3 ft. thick, and in modern furnaces it is strongly cased in cast-iron plates bolted together.

From the top of the hearth, the walls of the bosh are built up till they join the walls of the shaft above. As the

inverted cone would not be a stable structure, it is strengthened by bands of iron round every second layer of bricks, or is often completely cased in iron. In order to save the brick-work of the bosh it must be kept as cool as possible. The columns are therefore made as high as possible to allow free access of air. The bosh walls are made about 1 ft. 6 in. to 2 ft. thick, and when the furnace is to be driven hard, the bosh is cooled with water. This can be done by building into the masonry a series of blocks, either of iron or bronze, through which water can be made to circulate; or water may be circulated round the casing of the bosh. If a furnace is to stand well, the bosh must be kept cool.

The Bell and Cone.—The older furnaces were worked with an open top, the throat was surrounded with a sort of chimney, "the tunnel head," with openings for charging, and the gas was allowed to burn at the top of the furnace. Attempts were made to utilise the gas as far back as 1836. The invention of the bell-and-cone charging apparatus by Parry in 1850 solved the difficulty of drawing off the gas, without interfering with the charging, and from that time the utilisation of the gas became general. The gas, as already mentioned, is combustible and therefore is of great value as fuel. The bell-and-cone charging apparatus is now almost invariably used. The top of the furnace and the charging gallery is covered with iron plates up to the edge of the throat. An iron inverted cone about 6 ft. deep is fixed in the throat of the furnace, the slope being more or less steep according to the diameter of the throat of the furnace and the diameter required for the bell. It is now common to narrow the throat of the furnace considerably and use a very steep cone. The cone is of cast-iron, cast in four or more pieces with projecting flanges by which the parts are bolted together. Usually there is a separate bottom ring bolted on, which can be removed if necessary, so as to allow the bell to be lifted out. Inside the cone is hung a conical bell of such size that it will not draw through the bottom opening of the cone, so that when the bell is up, it presses all round against the cone, and when it is down, it leaves an annular opening all round. The bell may be of cast iron, but is usually composite, that is it consists of a cast-iron cap and a cast-iron bottom ring, cast in sections, the two being united by sheet-iron or steel stiffened,

if necessary, with steel rods. Such a bell is both lighter and stronger than one of cast-iron. The bell (Fig. 36) is suspended at the end of a beam by iron links or chains, additional safety chains being usually attached so that, in case the supporting link should give way, the bell would not be lost. At the other end of the beam is a balance weight heavy enough to keep up the bell, and an arrangement by which the bell can be fixed firmly in position. At the end of the bell over the cone is hung an iron basket in which a fire is kept burning, so that when the bell falls, the gas which escapes may ignite. The charge of ore fuel and flux is brought up in barrows and emptied on to the space between the bell and cone, care being taken to put the materials so that the charge in the furnace shall be as well mixed as possible. About

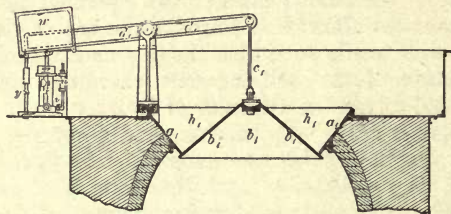


Fig. 36.—Bell and Cone Charging Apparatus: *b*, bell; *h*, cone; *d*, bell lever; *w*, balance weight; *y*, catch of fastening lever; *x*, cataract.

four or five tons of material is put on before the bell is lowered, and that is sufficient to outweigh the balance weight, so that as soon as the fixing catch or screw is released, the bell drops, the charge slips into the furnace, a rush of gas escapes from the top, which at once ignites, and the balance weight brings the bell back into position, where it is at once fixed. A little powdered material, such as purple ore or coke, is thrown round the bell to make the joint tight, and it is ready for the next charge. A bell working as described would be brought to rest too suddenly and would jar. To avoid this a cataract is often employed. This consists of a cylinder of water in which is a piston attached to the balance weight end of the bell beam, the upper and lower portions of this cylinder being connected by a small pipe in which is a stopcock. It is obvious that if the stopcock is closed, no

water can flow, and the piston and the bell cannot move. If the stopcock is opened, water can flow from one end to the other, and the bell can ascend or descend. The inertia of the water retards the motion, and thus diminishes the shock. The lowering and raising of the bell takes about 15 seconds.

Many other methods of operating the bell are in use. The bell can be made slightly heavier than the balance weight, and it can be brought up by a hand wheel working in a rack on the end of the beam, or by a screw or any other device. At one time the blast was put off when the bell was lowered, but this is now rarely done.

The bell needs some space so that it can be lowered, and this, with the depth of the bell itself, prevents the furnace being filled to the top. The space usually allowed is from 8 ft. to 10 ft.

Charging the Furnace.—The material for charging the furnace is put into barrows, each holding about 1 ton, either from ore bins or direct from the railway trucks. These are hoisted to the top of the furnace, wheeled by the charger to the cone, and emptied on to the bell. This method answers quite well for moderate outputs, but where a large output is required mechanical charging must be used. The material is carried up an inclined plane in a skip or bucket which is automatically emptied on to the bell (see Fig. 37). To prevent the charge always falling on the same part of the bell, which would lead to irregular working, a hopper into which the material is shot is fixed above the bell. This is arranged so that for each ascent of a skip it is rotated one-eighth or one-fourth of a revolution, and thus the charge is evenly distributed round the bell.

The Gas Mains.—Just below the charging platform, and opening into the space beneath the cone, is the gas main, which is an iron pipe 5 ft. or 6 ft. in diameter. This is connected with a valve box, from which descends the gas downcomer pipe, and to the top of which is attached a vertical standpipe opening into the air. By means of valves, the gas can be directed either upwards or downwards. Ordinarily, it is sent direct into the downcomer main, but when necessary it can be turned into the standpipe, at the top of which it burns. At one time the gas was always turned into the standpipe when the bell was lowered. This is now rarely done, as there

is always a pressure of gas in the furnace, and the gas escapes rather than air being drawn in. The gas carries over with it

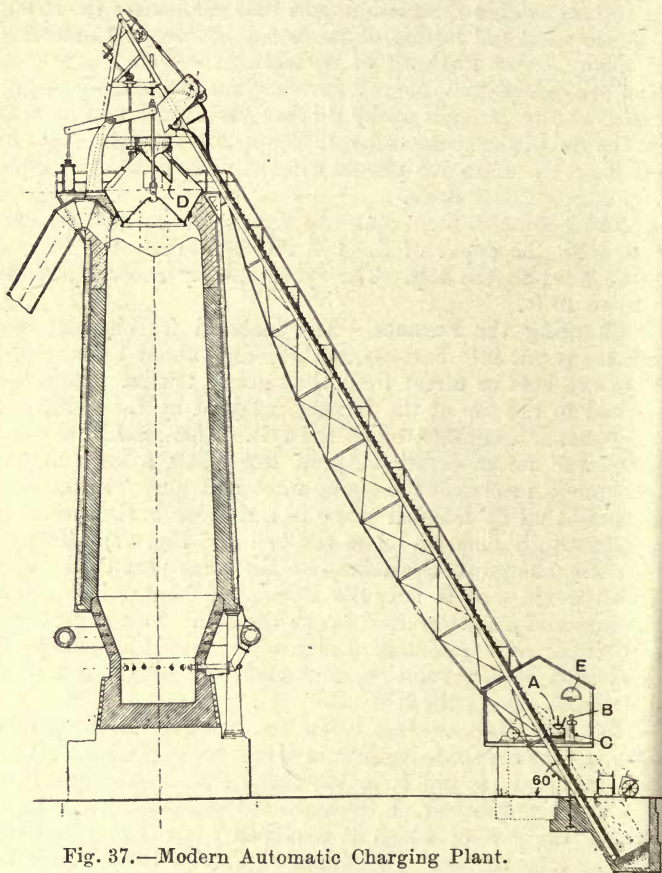


Fig. 37.—Modern Automatic Charging Plant.

dust from the charge, and to remove this it is passed through a dust catcher (see Fig. 29). This is simply a large chamber much larger than the gas main, so that the velocity of the gas is checked, and usually its direction is altered so that the

dust tends to fall out, and can be removed through the cleaning doors provided for that purpose.

Tuyere Openings.—Above the top of the hearth, a series of openings about 2 ft. wide and 1 ft. 6 in. high are left in the masonry (see Fig. 38). These are the tuyere arches or openings, and are to receive the pipes through which the air is sent into the furnace. The number varies; in modern furnaces it is eight, ten, or twelve, but in the old furnaces it was three or six. In modern furnaces the tuyere arches are evenly spaced round the hearth. In

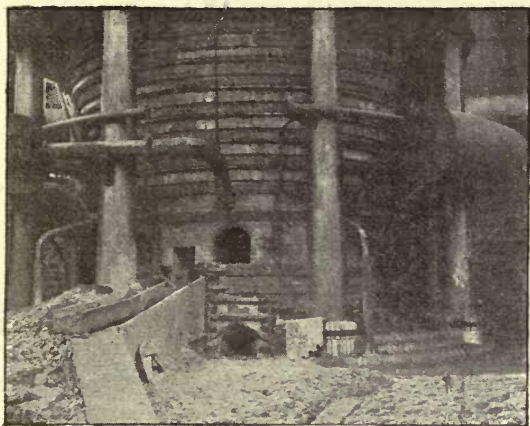


Fig. 38.—Front of Furnace, showing Tuyere Arches and Openings for Slag and Metal Tap Holes.

the older furnaces, in which the hearth could usually only be approached by four arches through the heavy masonry base of the furnace, tuyere arches were provided in three of these, the fourth or front of the furnace, where the tap hole is, not having a tuyere, or at least only a small one, called a "monkey."

The air from the blowing engines and hot-blast stoves is brought up to a main which almost encircles the furnace, and is called the "horseshoe" main. It is of iron, and is lined with firebrick, and sometimes is also covered with a

non-conducting coating. The horseshoe is almost always carried on iron brackets bolted to the furnace columns, or in some modern furnaces it is suspended by iron links from the top girders. Opposite each tuyere arch, a vertical pipe descends to the tuyere level, and is provided with a sliding valve by which the air can be cut off from the tuyere when necessary.

The Tuyeres.—The tuyere is an iron or bronze pipe about 3 ft. long, and having a diameter at the small end of from 3 in. to 8 in., according to the amount of air to be sent into the furnace. A very common size is 4 in. This is connected with the downcomer by means of an iron tube. In the days of the cold blast a leather pipe was used, which was called a "goose-neck," and the name is sometimes used for the connection.

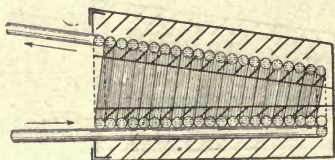


Fig. 39.—Scotch Tuyere.

The horizontal pipe must be fitted to the vertical downcomer pipe in such a way that it is air-tight, and at the same time can be quickly and easily removed. The end of the downcomer pipe is usually made conical, and is machined smooth, a hole to receive it being made in the upper side of the tuyere pipe (see Fig. 39). An iron link hung on studs from the downcomer is passed under the horizontal pipe and is screwed or wedged into position, so that it is firmly held. At the end of the horizontal pipe is an opening closed by a slide, which can be opened to allow the workman to clear the tuyere with an iron rod, should it become stopped. In the centre of this is a hole closed by mica or blue glass, through which can be seen a bright spot (the eye of the furnace), from which the workman can judge if the tuyere is properly open.

Water-cooled Tuyeres.—When the cold blast was used, the tuyere was laid in the tuyere arch and luted in with clay; but with the hot blast as now used, combined with

the heat of the furnace, the iron pipe would be rapidly destroyed. To prevent this, it is surrounded by a water jacket, which keeps the blast pipe enveloped in flowing cold water. The Scotch tuyere (Fig. 39), which is now generally used, was invented by Condie in 1829. It consists of a coil of wrought-iron pipe embedded in a mass of cast iron, with a hole in the centre in which the tuyere nozzle rests. The Staffordshire or box tuyere (Fig. 40) consists of a conical iron box with a hole through centre for the tuyere nozzle, a constant stream of water being kept running through. In a modern form, instead of keeping the box filled with water, a fine spray is delivered which keeps the whole cool. This spray tuyere has the advantage that there is no large mass of water to flow into the

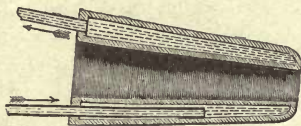


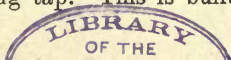
Fig. 40.—Staffordshire Tuyere.

furnace should the tuyere break. Box tuyeres, whether water or spray, are best made of bronze, as being much less likely to crack than cast iron. In the forms of tuyere described, the water is delivered under pressure, and in case of fracture the water will flow into the furnace and may cause an explosion; to avoid this, a vacuum tuyere has recently been introduced. The water is drawn through by suction by means of a pump, so that should the tuyere fracture, water does not flow out, but gases are drawn in and can be at once detected.

With the hot blast now often used, the single water tuyere is not sufficient, and it is surrounded by a second water tuyere or cooler, commonly called a "jumbo."

The water from the tuyeres always flows out into an open channel, so that the workman can judge if it is flowing correctly and is about the right temperature.

Slag Tap.—At the top of the hearth, a few inches below the bottom of the tuyere arches, another opening is left in the masonry for the slag tap. This is built up with brickwork,



a hole being left for tapping out the slag. Frequently a water tuyere is fitted into this hole. As the furnace works, the metal sinks into the hearth with the slag above it. As the slag and metal accumulate they rise, and if not removed the slag would soon reach the level of the tuyeres. To avoid this the slag hole, which has been stopped with clay, is opened and the slag is run out. The hole is then closed, and the

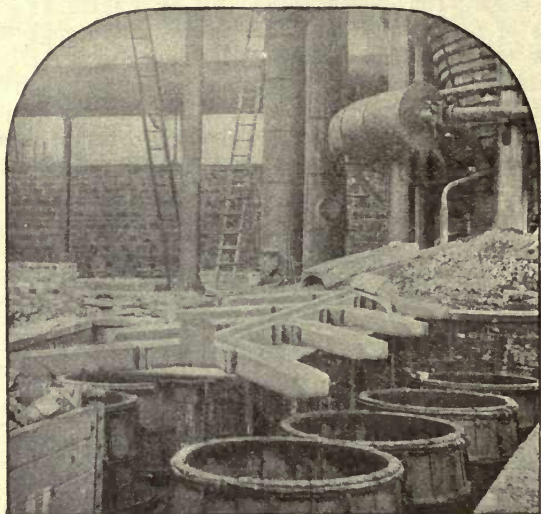


Fig. 41.—Slag Runners with Circular Slag Bogies.

tapping is repeated every hour or so from the time the slag reaches the necessary level until the metal is tapped.

In front of the slag hole a sloping channel (Fig. 41) (the cinder or slag fall), is made by which the slag is carried away. The slag is often formed into large blocks by running it into a slag-tub or bogie (an iron truck with movable sides), so that, when the tub is filled and the slag has solidified, the sides of the cinder-tub are lifted away by means of a crane, or if hinged are turned downwards. The mass of slag is then lifted from the bottom of the slag-tub or bogie on which it stands, and conveyed to the cinder-heap; or the bogie itself is drawn to the cinder-heap, and the block there thrown or tipped off

on to the heap. As the slag-bogie is filled, it is replaced by an empty one, or the channel is diverted so as to run the slag into another standing alongside the one just filled.

In Staffordshire, the slags collect in a cavity or basin in the ground or floor of the casting-bed, and known as the roughing-hole, from whence, after solidification, the slag is lifted into waggons and taken to the cinder-tip. To facilitate the removal of the slag, a conveyer is now frequently used. This consists of a series of shallow iron moulds carried on an endless belt, passing under the end of the slag shoot.

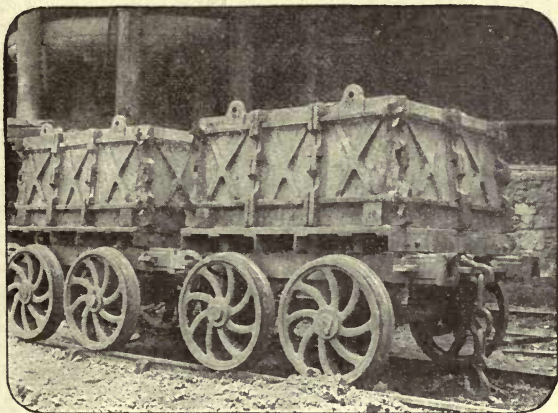


Fig. 42.—Square Slag Bogies.

The slag is allowed to flow continuously, and the moulds move at such a rate that each is filled as it passes under the shoot. The slag is solidified by a spray of water, and is automatically delivered from the conveyer to a truck in which it can be carried away to the slag tip.

Metal Tap.—At the bottom of the hearth, usually near the slag hole but not vertically under it, another opening is left in the masonry; this is also closed up with brickwork, a hole about 6 in. in diameter being left, which is stopped with clay. When the metal rises nearly to the level of the slag hole, the furnace must be tapped. The workman places the end of a crowbar, resting on an iron

rod, against the clay of the tap hole, and by means of a sledge drives it in. As soon as an opening is made, the iron begins to flow. When the iron is all out it is followed by the residual slag, and as the liquid falls below the hole,

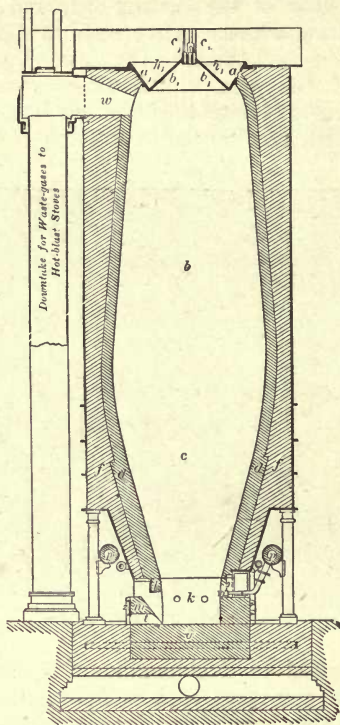


Fig. 43.—Blast Furnace with open Front, Vertical Section.

air escapes and sparks are ejected. The hole is now closed. The workman takes a lump of clay which has been mixed with water so as to be plastic, and throws it against the opening, pressing it with a rod so as to make it solid. A second lump is added and pressed in so as to make the tap hole quite secure. In America the clay is forced into position by means of a pneumatic "mudgun."

The furnace can be tapped every six, eight, or twelve hours according to the capacity of the hearth and rate of reduction. In Scotland the furnaces are tapped every twelve hours, and each tap yields about 25 tons of iron.

Older Open Front Furnaces.—In the older furnaces the arrangement was a little different. The hearth was not completely enclosed, but the front was extended a little beyond the furnace, the weight above being carried by an arch thrown across the space and called the “t ymp” arch. This arch was often replaced by an iron girder kept cool by the circulation of water through it. The front of the hearth was closed by a vertical wall, the “dam” strengthened by an iron “dam” plate through which the tap hole was made. In the top of the dam was a notch or channel, the slag notch for the flow of the slag. The space between the t ymp arch and the top of the dam was kept closed with clay and sand, except when the furnace was at work, save for a hole for the flow of the slag.

The Pig Bed (Fig. 44).—In front of the furnace is a space about 40 ft. by 20 ft., covered to the depth of about 1 ft. 6 in. with a slightly binding sand, similar to the moulding sand used in the foundry, the surface being slightly sloping away from the furnace. As soon as the pigs have been removed, the bed is prepared for the next charge. The sand is levelled, and by means of wooden moulds a series of D-shaped cavities about 3 ft. long, 4 in. wide, and 4 in. deep are made in the sand (see Fig. 44). A boy hammers in the pattern till it is level with the surface, and when he has put in a whole row, he carefully removes them one by one, leaving a row of moulds. Then he cuts channels *b* connecting the ends of these, and these channels in their turn are led into a larger channel *d*, which leads to the tap hole of the blast furnace.

When the furnace is to be tapped, all the cross passages *b*, except the bottom one, are closed by means of iron plugs covered with clay and having long handles attached to them. The metal therefore flows along *d* and fills the bottom series of moulds. As soon as these are full, the second channel *b* is opened and a plug is put across *d* to prevent any more iron flowing down, and this is repeated until all the iron is out. As soon as slag begins to flow, it is directed to the slag

channel, and when the tapping is complete, the surface of the pigs is covered with sand, or sometimes they are cooled with water.

Directly the metal is cool enough to handle, workmen, with their hands protected with pieces of leather, set to work to remove the pigs. The pigs in the moulds *c* are broken from the metal in the channels *b*, the metal being broken up into pieces of convenient size, and these and the pigs are at once transferred to stacks, or to railway trucks for removal. When they are all removed, the bed is prepared

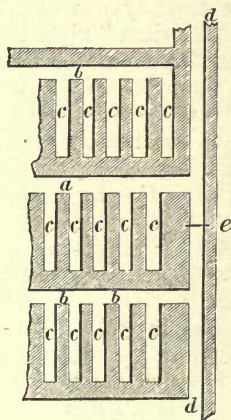


Fig. 44.—Plan of Pig Bed.

for the next charge. The pig bed is usually placed at a convenient elevation so that the pigs can be readily loaded into trucks. Each pig will weigh about 1 cwt., so that for 25 tons, 500 pig moulds will be necessary.

To facilitate the removal of the iron to the trucks, mechanical appliances are now largely used. In some works an overhead crane is arranged along the whole length of the pig bed, and in others a powerful jib crane is run along the end of the pig bed. As soon as the iron is cool enough, a lever is put under *b* to raise it a little, a chain is slipped round or a hook is slipped under, and the grid, consisting of *B* with the twenty to twenty-five pigs attached, is carried

bodily away and stacked. When the pigs are required, the grid is again lifted by the crane and taken to a pig breaker, by which the pigs are rapidly broken off. This arrangement saves both time and labour.

Metal Mixers.—In steel making, the iron is required in the molten condition ; it is therefore a waste of time, labour, and fuel to allow the metal to cool, lift the pigs by hand, and melt it again. To avoid this, metal mixers have been introduced.

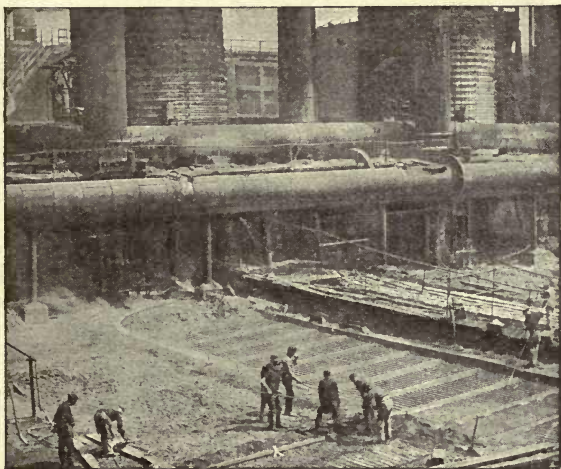


Fig. 45.—Front of Furnace, showing Pig Bed.

The metal mixer is a large vessel made of sheet steel and lined with refractory firebrick, of such size as to hold from 100 to 500 tons of metal. It is always arranged so that it can be tilted to pour out the metal. One form shown in Fig. 46 consists of a nearly semi-cylindrical vessel resting on rollers, so that it can be easily turned by means of a hydraulic ram. It is provided with two openings, one to receive the metal, the other forming a spout from which the metal is poured. Usually, gas is brought to the ladle so that heat can be applied if there is any danger of chilling. The pig bed is abolished, and in place of it rails are laid at a low level, so that a ladle capable of holding the whole charge of the

furnace (50 or 100 tons) can be run under the tap hole. The metal is run into the ladle; this is drawn by a locomotive to the mixer, and either by tilting the ladle or running the metal out of a tap hole, the metal is transformed to the mixer, whence it can be poured into another ladle for conveyance to the steel works or use as required.

The mixer has the great advantage in that it gives iron of more uniform quality of metal than can be obtained from the blast furnace direct, because the products from various

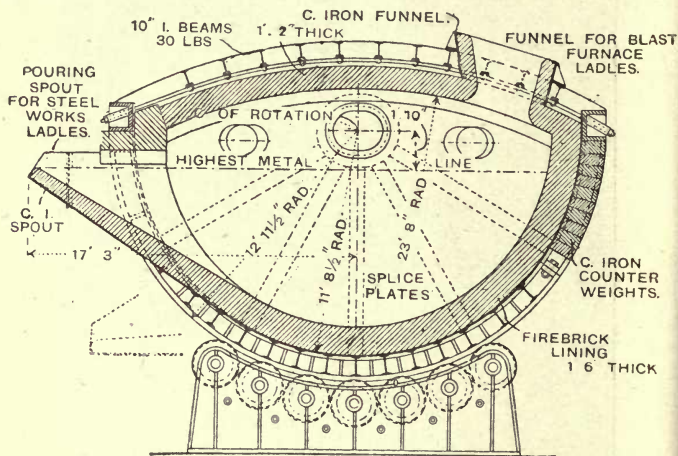


Fig. 46.—Metal Mixer.

furnaces or various taps, being mixed, accidental variations to a certain extent compensate one another.

Casting Machines.—For dealing with large casts of metal, casting machines are used to some extent in this country, and largely in America. Many forms have been designed, but the best known and most largely used is the Uehling. This is used always in conjunction with a mixer, into which the metal is run from the furnace. A series of iron moulds carried on endless chains passes under the mixer at such a rate that each is filled as it passes—the usual rate being about 15 ft. per second. As the moulds pass from before the mixer, they are sprinkled with water to cool the pigs, and as the

endless belt passes over the end pulley, the pigs fall out into a trough of water, whence they are carried by another endless belt at right angles to the first, and delivered into trucks. As the moulds return, they are cooled and prepared for the next charge by being coated with milk of lime sprayed by means of compressed air.

The belt is about 100 ft. long, the moulds are 1 ft. 10 in. by 10 in. by 6 in. deep, and the metal is cast into flat cakes about $\frac{3}{4}$ in. thick, which solidify rapidly.

Such a machine will handle 1 ton of iron per minute continuously, and the machine will run for months without repair; the moulds last about six months and are easily replaced. Three men work the machine on 12-hour shifts. The average cost of handling a ton of pig iron is said to be 3d. or $3\frac{1}{2}$ d. The pigs are perfectly clean and free from sand, but owing to the sudden cooling they tend towards whiteness, and the grade cannot be determined from the fracture. For this reason the machine is not likely to come into use in this country for casting foundry pig.

Hoists.—Hoists, lifts, or elevators are necessary when the loaded trucks cannot be run directly to the level of the charging platform. The more modern plant is generally laid out for some form of the perpendicular lift, but still, as at Barrow-in-Furness and numerous other works, a modification of the inclined plane has been used for raising the ore, fuel, and flux from the ground level to the charging platform. At Barrow the inclined road is carried on a pair of bowstring girders placed at an angle of from 25° to 30° with the horizontal, and the road is fitted with two sets of rails, on one of which the loaded truck ascends, while the empty one descends the other. The carriage consists of a horizontal platform, supported on a triangular frame fitted with two pairs of wheels, of which the front ones are smaller than the back. The lift is arranged so that when the carriage is at the bottom of the inclined plane it is received in a pit in the ground, and its platform is then on a level with the floor of the yard or shed, and the four or more iron wheel-barrows, in which the charge is usually placed for elevation to the furnace top, can be wheeled directly on to the platform; and in like manner, when the lift has made its ascent up the incline, it stands so that the platform of the carriage is level with

the charging platform, and the wheel-barrows can be wheeled directly on to the top. The motive power for this elevator consists usually of a pair of steam engines, working through friction gearing a winding drum about 12 ft. in diameter, around which passes a wire rope, the two ends of which are attached respectively to the ascending and descending platforms, while the action of the engine is controlled by steam brakes.

Of the perpendicular lifts, the water-balance is still in use at some of the older furnaces, where a natural fall of water is obtainable, under which condition it is an economical and simple arrangement, although giving some trouble, owing to the difficulty of keeping the tanks water-tight; whilst if a pump has to be employed in lifting the water to the top of the furnace for introduction into the tanks, its advantages are seriously diminished. In the water-balance arrangement two cages or platforms are employed, beneath each of which is fixed a water-tight tank, capable of containing sufficient water to enable it when filled to draw up the other platform with its empty tank, and the load of ore or fuel. The two cages work between guides, and are respectively suspended from the extremities of a wire rope passing over guide pulleys. Thus, when one cage is at the furnace platform, and the other at the ground level, the tank of the latter is emptied of its water through a valve fitted in the bottom of the tank, while the tank of the former is filled with water. In this manner sufficient weight is added to the top cage to draw up the other cage with its load of charging materials from the bottom to the top of the lift.

Pneumatic or compressed-air lifts are sometimes employed in which the areas of the pneumatic cylinders are adjusted so that a pressure of from $3\frac{1}{2}$ lbs. to 6 lbs. or 7 lbs. per sq. in., as occurs in the blast-main supplying the blast furnaces, is sufficient to elevate the required load. In other arrangements, double-acting air pumps by which air is forced into or withdrawn from the cylinders as required, are employed. In pneumatic lifts compressed air or the atmospheric pressure working against an exhaust is used. The best known of these is that of Mr. Gjers (F.g. 47). In this the platform surrounds a circular tube about 3 ft. in diameter, and is attached, by means of wire ropes working

over pulleys, to a piston working in the tube. To raise the platform the air is exhausted from behind the piston and the pressure of the atmosphere forces it down. To bring the platform down, air under a pressure of about 2 lbs. is forced beneath the piston.

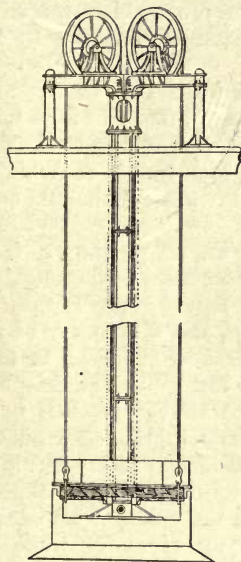


Fig. 47.—Gjer's Pneumatic Hoist.

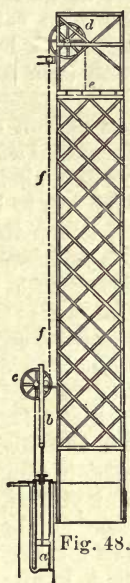


Fig. 48.

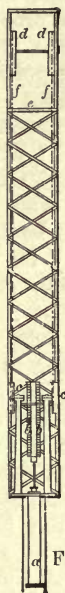


Fig. 49.

Figs. 48 and 49.—Hydraulic Hoist, Side and End Elevations.

In hydraulic lifts, or hoists, a ram, actuated by pressure from a hydraulic accumulator, is connected with a chain and system of pulleys whereby the movement of the load to be lifted is some six or eight times greater than that of the ram by which it is actuated, according to the multiplying powers of the chains and pulleys employed. Figs. 48 and 49 show a simple form used in America; the ram of a hydraulic cylinder *a* terminates in two racks *b*, which gear into two pinions on the same axle as the pulleys *c*, round which the wire rope *f* passes from the table *e* over the guide pulleys *d*, so that

by properly proportioning the diameter of the pinion into which the rack gears, to that of the pulleys or drums *c*, any desired velocity of ascent can be given to the cage.

Direct-acting steam hoists are now generally used. The cage works in guides like an ordinary colliery cage, and is provided with safety catches to prevent accident; the cage is supported by a wire rope which passes over a large pulley and then round a drum worked directly by an engine.

For each ton of iron obtained from, say, Cleveland ore, about 4 tons of material will need to be lifted; or for a furnace making 50 tons a day, about 200 tons in addition to the weight of the cage, which has to be lifted each time. Assuming two tons to be carried each time, the lift must make 100 ascents per day for each furnace.

Blowing In.—Before blowing in, or putting a furnace into blast, the masonry of the structure must be thoroughly and slowly dried to prevent cracking or fissure of any portion of it. Then the tuyere holes are built up, and a quantity of rough old timber introduced into the furnace, sufficient to fill the hearth to a depth of 5 ft. or 6 ft., and on this sufficient coke is placed to fill the boshes. The timber is then ignited, and the combustion rapidly extends to the coke above it, when successive layers of coke and limestone are introduced, until the furnace is about one-third filled, the limestone serving as a flux for the ashes of the coke. This charge is followed by light burdens made up of about three parts of calcined ore, with one part of limestone and two parts of coke, thus gradually filling the furnace up to the throat. Then blast-tuyeres of about one-half the diameter of those to be eventually used are inserted, and the blast put on at about one-fifth of the normal working strength. This condition is continued for from thirty-six to forty-eight hours, after which the blast nozzles are changed for others of $\frac{3}{4}$ in. or 1 in. greater diameter, which deliver a proportionately larger blast; at the end of twenty-four hours tuyeres larger by a further $\frac{3}{4}$ in. in diameter are inserted; and a further increase of $\frac{1}{2}$ in. in diameter is made to the blast nozzles at the end of about the third week. But it is not until some four or five weeks after the first introduction of blast that the full working pressure and volume of blast are employed, and in the interval

the furnace is run on light burdens which are increased with each increase in the strength of the blast.

Slags first appear twelve hours after the admission of blast to the furnace, but there is no metal until the end of twenty-four hours; then it collects slowly and is tapped out as is necessary, but it is only after three or four days that the metal can be tapped from the furnace at regular intervals. When Cleveland furnaces are in regular blast the charge takes about seventy-two hours to pass from the top or charging plates to the hearth, but in some of the small furnaces, or where the driving is rapid, the time is much less.

The furnace having once been put into blast, continues at uninterrupted work until it is necessary to stop for repairs or some other cause. When, owing to a temporary scarcity of ore, fuel, or the like, it becomes necessary to stop the working for a short time, the throat and tuyere holes are closed with sand or clay, under which conditions the furnace may stand for three or four days without much danger; but if such delays are prolonged for one week or upwards, then troublesome obstructions are likely to form within the furnace, perhaps necessitating entire stoppage. A well-built blast furnace will run, under ordinary working and driving, for five or ten years without requiring to be blown out for repairs, but with the rapid driving now becoming general the life is very much shorter.

Blowing Out.—When a blast furnace is to be stopped—blown out—the burden is gradually reduced so as to increase the working temperature, and facilitate the fusion of any obstructions hanging within the furnace. The tubes and fittings from the throat are then removed, charging is discontinued, and the furnace allowed to burn itself down, care being exercised to take the last tapping of metal from the lowest possible point in the hearth. After blowing out a furnace which has been long in blast, there is often found in the bottom of the hearth an agglomerated mass of malleable steely-iron known as “bear” or “horse,” and similar but smaller masses will be attached to various points around the sides of the hearth. These masses contain besides iron, also manganese, carbon, silicon, and copper, as also nickel, cobalt, and occasionally traces of the rarer metals, and sometimes copper-coloured crystals of a nitro-cyanide of titanium.

Scaffolds, etc.—Scaffolds are obstructions in blast furnaces which arise from various causes, such as the faulty distribution of the charge, which prevents the regular descent, whilst, as the charge below the scaffold is working down, the mass above is left with a diminishing support, and the weight of superincumbent materials is at the same time constantly increasing by the addition of fresh materials at the furnace mouth. In these circumstances the obstruction at a certain point frequently gives way suddenly, and descends with considerable force to the hearth, constituting what is known as a “slip.” When a scaffold is discovered, the blast is eased so as to reduce the support from below due to the pressure of blast, and efforts are made to get down the scaffold without any sudden rush. Scaffolds also sometimes lead to the formation of a slight skew-back in the lining of the furnace owing to the erosion of the lining for some distance up, the effect of which is that a part of the stock or charge is held up, while other parts slide over it, and the furnace is thus found to work slowly and affords a diminished yield of metal. But scaffolds of the last class usually fill up with finely divided fuel and ore in good condition for rapidly melting, so that, after working for some time in this condition, the heat and attrition of the descending charge will work off the irregularity in the lining, and the materials of the scaffold will then work down quickly into the hearth, giving a much larger temporary yield to the furnace. A scaffold obstructs the free passage of the blast and the escape of the furnace gases, and tends to cool down the furnace and so thicken the slags. A slip, especially if the ore is very wet, may cause an explosion by the sudden evolution of steam as the wet material comes into the hot region of the furnace.

Amongst the causes contributing to the formation of scaffolds are: (a) faulty shape of the furnace; (b) the production of an imperfectly fusible slag; (c) too large a proportion of refractory ore in the charge; (d) bad fuel, such as a weak friable coke which crumbles away under the weight of the superincumbent materials; and (e) faulty charging, whereby the regular distribution of heat over the entire horizontal section is not maintained, owing to the larger pieces of coke collecting round the walls of the furnace, whilst the small and impermeable ore is concentrated in the centre.

CHAPTER IX.

BLOWING ENGINES.

A VERY large quantity of air is required for the blast furnace, and this must be supplied in a steady, continuous stream, and at a suitable temperature and pressure. In the early, very small furnaces, bellows worked by water power were at one time used, but these have been completely superseded by cylinder blowing engines driven by steam, gas, or water power.

Such an engine, as far as the blowing portion is concerned, consists of a cylinder, closed at both ends, in which works a piston. The cylinder is provided with two sets of valves at each end, one set opening to the air to admit the air from outside, and the other to allow the air to pass into the air mains, and called respectively the intake and outlet valves.

A few large cylinders or a large number of small cylinders may be used, according to convenience. In the older engines the tendency was to use a few large cylinders; now the cylinders are usually made smaller, and a larger number is provided.

Amount of Air Required.—The amount of air required can be easily calculated. One pound of carbon will require for its combustion to carbon-monoxide—and this is the conversion which takes place in the blast furnace—5·8 lbs. of air, or, as 1 cub. ft. of air under the normal conditions of temperature and pressure weighs ·0809 lb., 65·5 cub. ft. As the air will always contain moisture, and will usually be at a higher temperature than 0° C., it is often assumed that each pound of carbon will require 6 lb., or 76 cub. ft., of air, and these figures will be quite near enough for ordinary rough estimations. It must, of course, be remembered that the volume of a gas varies very much with changes in temperature and pressure, so that for the combustion of the same quantity of fuel a greater volume of air will be required when the temperature is high than when it is low, and also that as water vapour is much lighter than air, the weight of a cubic foot of ordinary moist air will be less than that of a cubic foot of dry air.

Assuming 5·8 lb. or 65·5 cub. ft. to be a correct estimate, this will be 5·8 tons, or about 147,000 cub. ft., for each ton of carbon consumed. Assuming the coke burnt to contain 90 per cent. of carbon, 5·22 tons, or 132,000 cub. ft., of air will be required for each ton of coke consumed.

The effect of moisture in the air will be to increase the quantity of air required, because the volume of water vapour required to burn a given weight of carbon is just twice the volume of the oxygen required for the same purpose, and also because, water vapour being lighter than air, the density of the mixture will be less than that of the dry air. The effect of moisture in reducing the temperature in the furnace has already been mentioned.

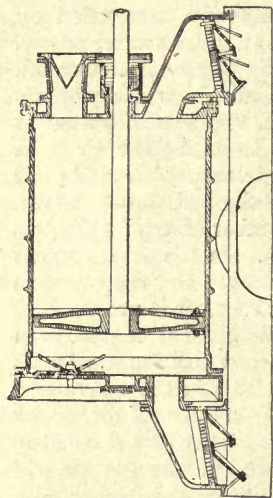


Fig. 50.—Blowing Cylinder, Section.

Blowing Cylinder.—The blowing cylinder for the supply of air is sometimes placed vertically and sometimes horizontally, the former being the more general. In the older type of blowing cylinders (Fig. 50) the intake valves were placed at the bottom and at the top, those at the bottom being small rectangular metal plates faced with leather or indiarubber, working on horizontal valve seats in the bottom cylinder cover, and held in place when closed by gravity. On the top cover valve boxes were usually fixed in which the valves hang nearly vertically, and work against valve seats in the boxes.

In many modern engines gravity valves are replaced by valves closed by a spring, and these are often arranged in a ring round the ends of the cylinder, which is lengthened at each end beyond the travel of the piston; and in some recent engines slide valves have been successfully used. The outlet valves by which the air passes to the air main are as a rule similar to the intake valves, but they have a much smaller area.

Beam Engines.—The early blowing engines were all of the

“beam” type. As a rule, the two cylinders are equidistant from the support so that the stroke is the same. Owing to the weight of the moving parts and the slowness of the motion, a flywheel is almost always used, this being attached by a connecting rod to the beam at a point near the steam end, or to a horn or projection at the end of the beam beyond the steam cylinder; these were called hornbeam engines. In the

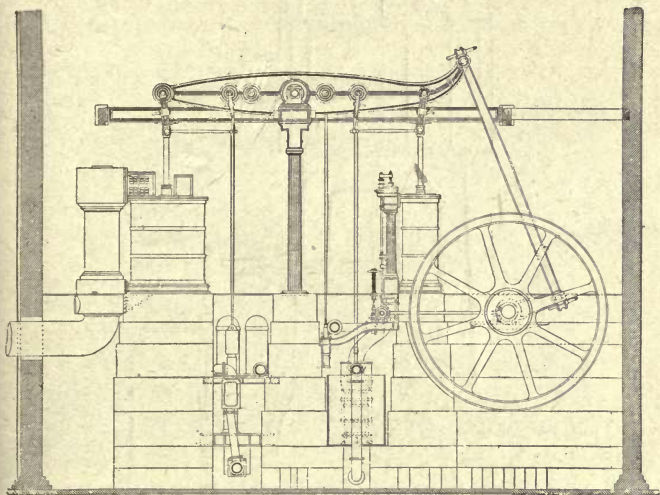


Fig. 51.—Beam Blowing Engine.

first erected the beams were of wood, but cast-iron was soon substituted, and the engines were much increased in size.

The beam blowing engine (Fig. 51) is very strong and durable, there being many at work to-day which have been running for fifty years. They can only be worked at a low speed—50 or 60 strokes per minute—and therefore the cylinders are made of large size, those of the famous Ebbw Vale engine being 12 ft. in diameter, and having a stroke of 12 ft., whilst 10 ft. in diameter and 10 ft. stroke is a common size. Frequently two such engines are placed side by side and coupled together.

Direct-acting Engines.—The beam engine is very

cumbersome, and it was soon suggested to replace it by a direct-acting engine in which the cylinders were placed in line either vertically or horizontally, and the pistons were attached to the same connecting rod. For blast furnace work, the vertical type is almost always

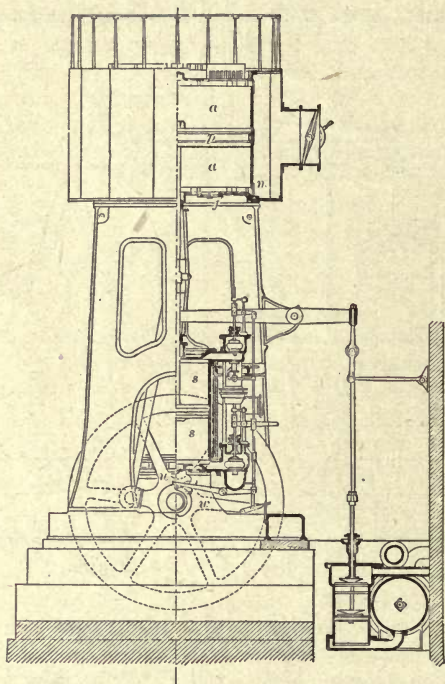


Fig. 52.—Blowing Engine, Elevation half in Section.

used. The cylinders of these engines are usually made very much smaller than those of beam engines, common sizes being 6 ft. diameter and 6 ft. stroke, and 5 ft. diameter and 5 ft. stroke, but they are driven at a considerably higher speed. The arrangements vary very much as to detail. Sometimes the blowing cylinder is placed at the top, and sometimes the steam cylinder. The flywheel is some-

times attached to a crosshead on the piston rod between the cylinders, or it may be attached to the lower end of the piston rod, which in this case is made to pass through the lower cylinder cover, by means of a connecting rod. The vertical direct-acting engine is the form now most generally used in British ironworks. Fig. 52 shows such a blowing engine half in section.

Double or triple expansion engines, with two or three cylinders, the steam passing from one to the other, are also used.

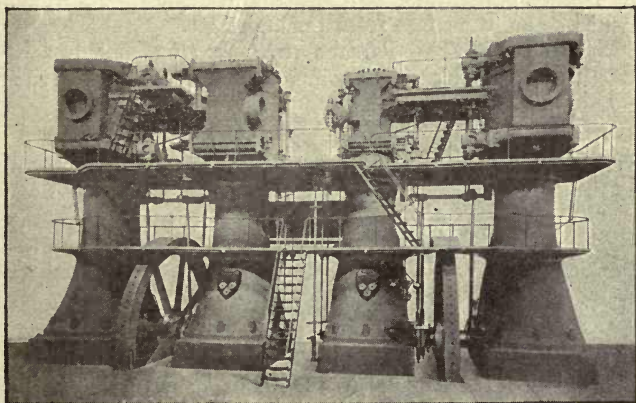


Fig. 53.—Pair of Quarter Crank Blowing Engines, as Fitted in Shop before Sending to Works.

The Quarter-crank Engine.—An engine built by Messrs. Richardsons, Westgarth and Company (shown at Fig. 53), and known as the quarter-crank engine, is coming largely into use. In this engine the steam and air cylinders are placed side by side and are connected by connecting rods to cranks on the same driving shaft, the flywheel being placed between the cranks. The cranks are not placed in line, but one a little in advance of the other, so that the two pistons do not reach the dead point at the same time.

Gas Engines.—One of the most recent innovations is the adoption of gas-driven engines for blowing purposes (Fig. 54). In the gas or internal combustion engine a mixture of a combustible gas and air is admitted to the

working cylinder, and is there ignited, the expansion of the gas produced by the heat of the combustion drives the piston forwards, so that the heat of the gas is utilised directly, and not by way of the generation of steam. At first, gas engines were built only of small size, and were driven by rich gas, such as coal gas; but gradually they have been increased in size, and designed for the use of poorer gas, such as ordinary blast furnace gas; and engines up to 1,000 h.p., driven by blast furnace gas, are now in regular use. The gas engines are usually built horizontal, and the gas must be thoroughly washed so as to be free from tar and dust.

Turbine Engines.—Parsons' turbine (Fig. 55) has been introduced as a blowing engine, a steam turbine driving a

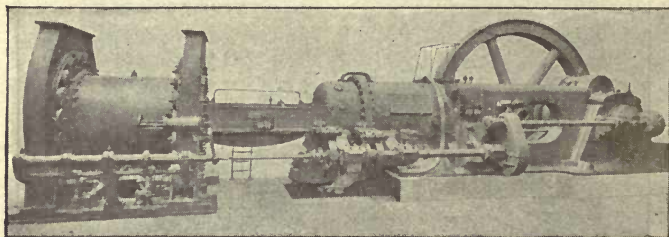


Fig. 54.—1,500-h.p. "Cockerill" Type Blowing Engine, with Double Acting Gas Cylinder. (Richardsons, Westgarth and Co.)

turbine blower. Engines of this type have now been fitted at several works. They are said to be very economical, and they give a much steadier blast than any type of piston engine, and they also occupy much less space.

Blast Regulation.—With any form of cylinder blowing engine the air will leave in puffs instead of in a perfectly uniform stream, owing to the varying speed of the blowing piston. To overcome this difficulty and to send the air forward in a steady stream, blast regulators were attached to the main. These usually consisted of large balloon-shaped vessels of sheet-iron having a capacity about equal to or a little less than the blast delivered per minute. The mass of air in the regulator has sufficient elasticity to take up the variations in pressure, being compressed when the pressure rises and expanding again as it falls. With modern plant no blast

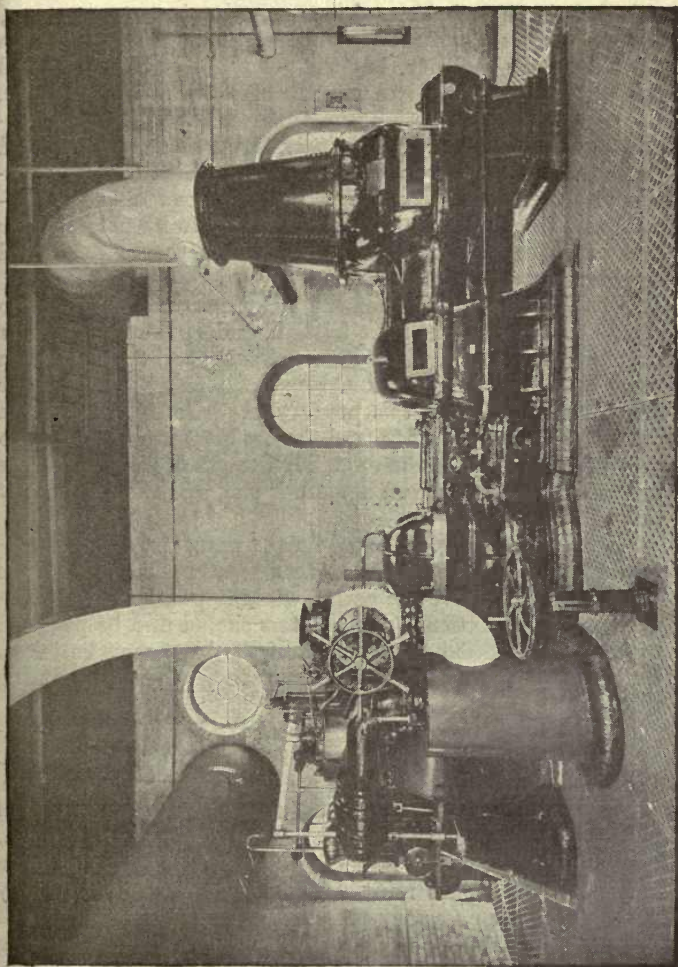


Fig. 55.—Parsons' Turbine-Blowing-Engine Capacity = 18,000 cub. ft. of air at 3,000 revolutions per minute.

regulator is necessary, the large mains and hot blast stoves containing enough air to act as regulators.

Arrangement of Engines.—In Great Britain, as a rule,

either one large engine is used to supply the air, or two or more, are attached to the same blast main. This method has the advantage of simplicity, but the great disadvantage that all the furnaces must be blown with the blast at the same pressure. In modern works, especially in America, each furnace is provided with its own engines, usually three, these being worked in pairs, and the third standing by for use in case of emergency. This system has the great advantage that each furnace can be given a blast pressure suited to its needs. This system will certainly become general as new works are erected or older ones are remodelled.

The Mains.—The size of the mains must be sufficient to carry the air with but little friction, and obviously, since air expands very much when it is heated, the hot blast main must be larger than the cold blast, and many failures have arisen from neglect of this precaution. The cold blast main carries the gas to the stove, and the hot blast from the stove to the furnace. The gas main takes the gas from the furnace top to the recovery plant, if there is one, and then to the hot blast stove.

Pyrometers, etc.—A pressure gauge, preferably self-recording, should be provided near the furnace so that the foreman may observe the actual working pressure at the furnace and its variations. Pyrometers should also be provided by which the actual temperature of the blast may be taken. Both pressure and temperature may vary very much during the day.

Blast Pressure.—The pressure of the blast must be sufficient to force the air through the furnace at the rate desired. For small charcoal furnaces the pressure may be as low as $\frac{1}{2}$ lb. per square inch. Ordinary Scotch furnaces with an output of about 300 tons a week use a blast pressure from $3\frac{1}{2}$ lbs. to 5 lbs., whilst in many modern furnaces a pressure of 11 lbs. or more is used. The engines must, of course, be capable of steadily maintaining the necessary pressure, and should be capable of giving more in case of emergency. Many modern blowing engines are capable of giving a pressure of 22 lbs. or more, but they are not worked regularly at the full pressure.

CHAPTER X.

HEATING THE BLAST.

THE introduction of hot-blast instead of cold-blast was attended with an economy in fuel and an increased make of iron by the furnaces, as already stated. A temperature of $1,500^{\circ}$ F. (815° C.), or a visible red heat, is now commonly employed. But in the production of these higher temperatures the stoves of the older type, with cast-iron pipes, are rapidly destroyed, and other stoves constructed upon the regenerative principle of Sir W. Siemens are always used. The first attempts to heat the blast were made by passing the air through iron boxes or pipes heated by separate fires.

U-Pipe Stove.—The first successful form of pipe-stove or oven consisted of a series of eight or twelve parallel arched pipes or tubes of cast-iron, of circular or elliptical section, arranged in an oblong chamber of fire-brick, along the sides of which were two circular mains fitted with sockets, into which the legs of the vertical pipes were fitted, while between the mains, and running the full length of the stove, was a rectangular fireplace. The cast-iron pipes were \cap -shaped, and stood vertically in the stove, with one foot in a socket upon the horizontal main running along one side of the furnace, and the other foot in a corresponding socket upon the main on the other side, and so the tubes spanned across the fireplace; for this reason it was called the U-pipe stove. There were stops or partitions in the horizontal main, so that the cold blast from the blowing engines, entering at one extremity of the one main, ascended from it through one set of \cap pipes passing across the stove, and then back again by the next set, and so on to the other end of the stove, the cold air thus passing several times over the fire before it left the stove by the hot-blast main to the furnace.

The pipes at first were heated by burning fuel upon the rectangular central fire-grate, but later burning blast furnace gas along the median line of the stove. In each case the flame and heated gases passed between and around

the stove-pipes, thus heating them on the exterior, and the products of combustion finally escaped from a chimney in the dome or roof of the stove. The better to absorb the heat, the stoves were sometimes divided into two chambers, by a partition wall reaching from the floor almost to

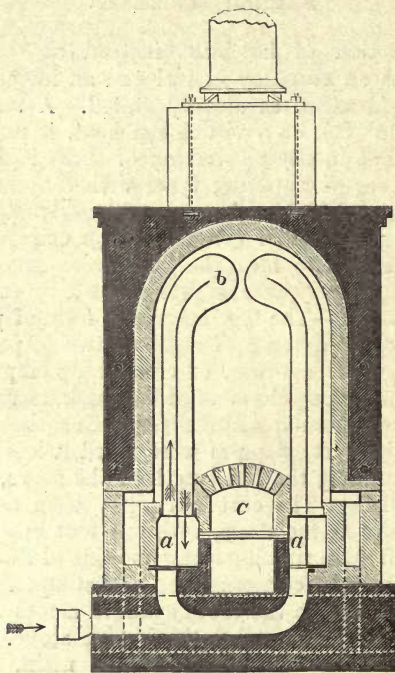


Fig. 56.—Pistol-pipe Hot-blast Stove, Vertical Section.

the roof, so that the flame and gases first circulated through one half, and then passed over the division wall, and through the second half of the stove, before escaping by the chimney. The stove-pipes frequently broke by their own contraction and expansion as the temperature varied, and to mitigate this, a suggestion was made to place one of the horizontal mains upon rollers, so that it was free to move inwards or outwards with the expansion and contraction of the legs.

Pistol-pipe Stove.—The pistol-pipe stove is another form of the cast-iron pipe arrangement used for some of the furnaces in Cleveland, Scotland, France, and Germany. In this stove (Fig. 56) the two legs of the pipes in the previous arrangements are replaced by a single pipe, divided, as shown, by a septum or dividing rib, *b*, reaching from the mouth almost to the top or closed end of the pipe, and so practically dividing each pipe into two tubes. The closed end is enlarged slightly and bent over somewhat, so that its form bears some resemblance to the stock of a pistol, hence the name. When the stove is heated by solid fuel, these pipes are arranged on each side of a rectangular fireplace, *c*; and the pipes on each side of the stove lean over towards each other, so as almost to come into contact; thus the cold air enters at the bottom of the stove into one division of the box *a, a*, in which the pipes stand, and, since these are divided into compartments by divisions corresponding to those in the pipes, the air or blast ascends in succession through one side, as shown by the arrows, and descends along the other side of the division in each pipe, until it finally passes out from the end of the stove to the hot-blast main, and thence to the furnace.

The heating surface supplied by pipe-stoves is usually calculated so as to allow about one square foot for each cubic foot of blast passing through the pipes per minute, if the stoves are fired with coal, or about 10 to 20 per cent. more if fired with the waste gases. Many other forms of pipe stoves were introduced at various times, but none of them is now in use, having been completely displaced by the modern fire brick stoves on the regenerative system.

The use of cast-iron pipe-stoves was attended with serious loss and inconvenience, arising from the frequent fracture of the pipes due to the repeated alternations of temperature to which they are subjected, and to the expansion and contraction of the pipes during the working of the stoves. A further cause of fracture is the rapid oxidation and destruction of the pipes at the high temperatures.

FIRE BRICK STOVES.

Cowper Stove.—Of the fire brick stoves, the Cowper stove, invented by Mr. Cowper, of Middlesbrough, was

the first. It consists of an outer wrought-iron casing (Figs. 57 and 58), lined internally with several rings of fire-brick, built in half-brick courses, the stove being closed by a dome-shaped roof, also lined with fire-brick. Within this casing is built up a circular fire-brick combustion chamber, *m*, at the base of which are the inlet valves *G*, for the gases from the blast furnace and the valve *A*, admitting the air

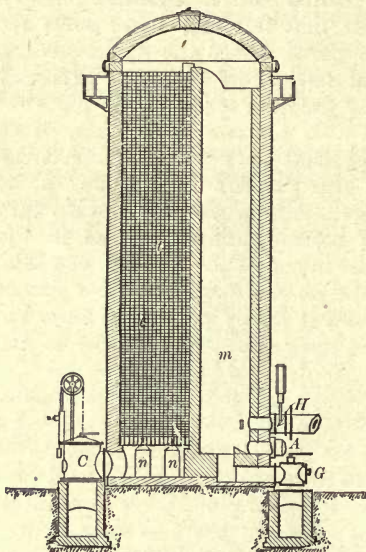


Fig. 57.—Cowper Hot-blast Stove,
Sectional Elevation.

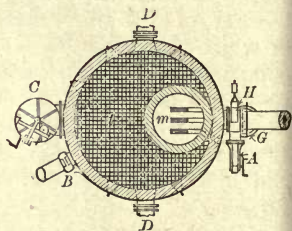


Fig. 58.—Cowper Hot-blast Stove, Plan.

necessary for the combustion of the gases; whilst *H* is the outlet valve for the hot-blast. The body of the stove is filled by the regenerators or fire-brick chequer work *t*, at the base of which are the cold-blast valve *B*, and the chimney valve *C*, while at *D*, *D* are the cleaning doors. Placed at intervals over the bottom of the stove are dwarf pillars, *n*, of brick or iron, which carry short girders upon which rest a series of strong grids, which support the regenerators. In the original form of stove the regenerator bricks were 2 in. thick, 5 in. wide, and 12 in. long, and were arranged

so as to leave vertical open passages about 4 in. square through the entire height of the stove—that is, from the grids at the bottom to within a few feet of the domed top of the stove. When the chimney-valve *C* is open, gas and air are admitted at the bottom of the combustion chamber by the valves *G* and *A* respectively; the gas immediately ignites and is split up into three currents by the divisions shown in Fig. 58; thus a more complete mixture of the air and gas is effected, and an immense flame ascends through the flame flue, spreading out beneath the dome over the top of the regenerators. The flame and heated products of combustion then pass slowly to the bottom of the stove, through the numerous square passages in the chequer work, before they escape by the chimney flue. In this manner the mass of brickwork within the stove, absorbing heat from the incandescent gases in contact with it, attains to a very high temperature, the upper layers of brickwork naturally becoming hotter than the brickwork near the bottom of the stove, while the products of combustion are reduced in temperature as they descend through the stove and finally pass out by the chimney flue *C*, at a temperature of about 400° F. (240° C.).

The stove having thus been heated by the combustion of the blast furnace gases within it, and by the passage of the products of combustion through it, the gas-valve *G*, the air-valve *A*, and the chimney-valve *C* are all closed, while the cold-blast valve *B* at the bottom of the stove is opened, as is also the hot-blast valve *H* near the bottom of the flame flue. The cold air then enters the stove at the lower or cool end of the regenerator, and slowly ascends through the height of the stove along the small but numerous passages of the regenerator, and from thence down again through the combustion chamber, and so out by the hot-blast valve *H* to the blast main and thence to the furnace tuyeres. The cold air thus traverses the stove in exactly the reverse direction to that followed by the gases in heating the stove, whereby the cold blast slowly takes up the heat given out by the brick surfaces of the stove, and the blast is quickly raised to a temperature of 1500° F. (815° C.) or redness. Since the blast first enters at the lower or cooler part of the stove, it is gradually heated to the above temperature without materially

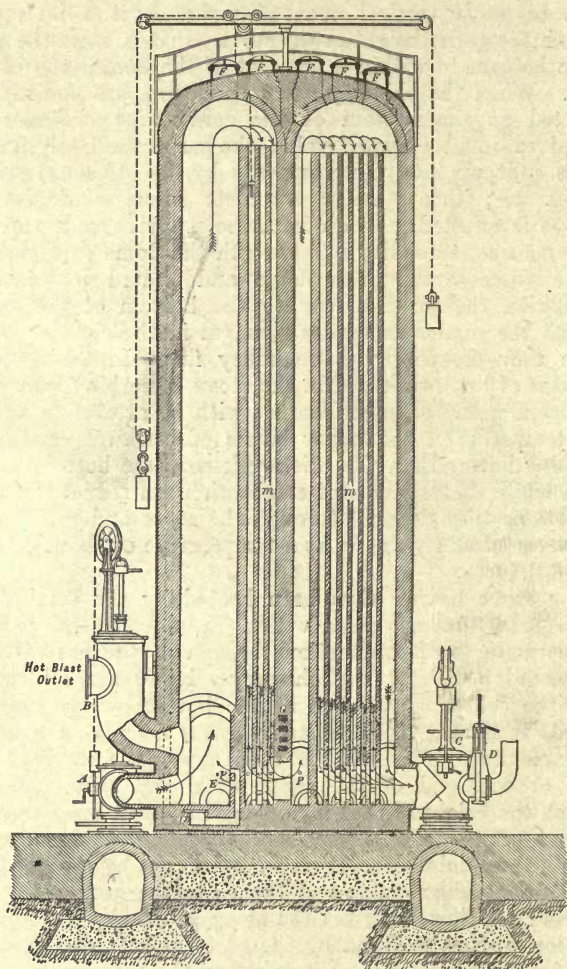


Fig. 59.—Whitwell Hot-blast Stove, Sectional Elevation.

cooling the upper layers of brickwork in the regenerators, before the lower parts have lost much of their heat, and in

this manner the stove affords a fairly regular temperature, the upper part never falling below redness.

Two stoves are worked in conjunction, so that whilst one stove is being heated by the combustion of the blast furnace gases, the cold air is being driven through the other and heated to the temperature required for the blast furnace. Two stoves are necessary for one furnace, but three stoves can be made to serve two furnaces. The main from the stoves to the furnace is usually made about 3 ft. in diameter, and is lined with a 9-in. course of fire-brick to prevent cooling and corrosion.

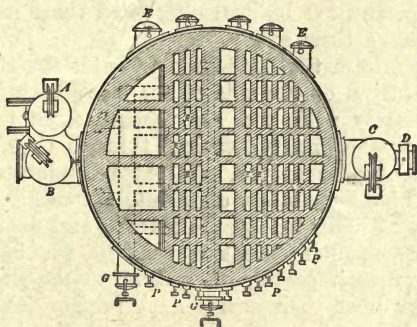


Fig. 60.—Whitwell Hot-blast Stove, Sectional Plan.

In the modern Cowper stoves bricks of special form are used so as to give a series of vertical passages and thus give no facilities for the lodgment of dust. Cowper stoves are from 50 ft. to 75 ft. high, and from 20 ft. to 25 ft. in diameter, the larger stoves having about 75,000 sq. ft. of heating surface.

Whitwell Stove.—The Whitwell stove differs from the Cowper principally in the arrangement of the heating surfaces, which in this case consist of broad spaces and flat walls. The air is often admitted at several points, so that the combustion of the gases first entering the stove is only completed after they have traversed partly through the stoves.

The Whitwell stoves have been built in England up to 68 ft. in height, by 22 ft. in diameter, and containing 26,000 sq. ft. of heating surface ; while in America they are working

as large as 70 ft. in height and 21 ft. in diameter, with a heating surface of 30,000 sq. ft. These stoves (Figs. 59 and 60) have an outer shell or casing of wrought-iron plates, lined internally with fire-brick, while, to permit of the expansion and contraction of the lining, there is left a space of 1 in. between the iron casing and the lining, this being usually filled in with granulated slag. Within this cylindrical chamber is built a series of long narrow vertical walls forming chambers, *m*, communicating with each other at the top and bottom. The partition walls nearest to the point where the blast furnace waste gases first enter become hotter than the rest of the stove, and are built thicker than those near to where the gases make their exit.

The gases from the blast furnace enter the stove through the valve *A*, fixed on the side of the stove casing, and, meeting immediately with the air passing from the air-valves (also fixed to the external casing) through the air-courses *G*, combustion at once ensues, and the incandescent gases rise to the top of the chamber, distribute themselves over one or more walls, as indicated by the arrows, and descend through one or more smaller chambers towards the bottom of the stove, the gases imparting their heat to the fire-brick walls as they pass over their surface. A further supply of air is admitted, and mixes with the gases at the bottom of the stove; here more complete combustion ensues, and the products re-ascend either by another wide combustion chamber or, in the older designs, through two or three of the narrow chambers, and finally descend through the remaining chambers to the chimney-valve *C*, from whence the gases pass away to the chimney at a temperature of from 300° to 400° F. (149° to 204° C.). The communications between the several chambers, through which the gases pass at the top and bottom, are placed so as to cause them to travel as much as possible towards the sides of the stove, and so render the total heating surface as effective as possible. In the casing of the stove, and opening through the lining, are a row of eye-pieces, *P*, opening into the several chambers, so that the state of the stove may be observed, and the combustion of the gases regulated accordingly.

In the latest Whitwell stoves the products of combustion leaving the combustion chambers distribute themselves over

the whole of the passages and pass downwards to the flue, the gas passing therefore only once down the stove. When the stove is sufficiently heated, which happens after a lapse of from one to two hours, the gas-valve is closed, and then the chimney and air-valves are also closed, while the cold-blast valve D, and the hot-blast valve B, are opened, whereby the blast enters the stove at its coolest part, and traverses the chambers in the reverse direction to that pursued by the gases in heating up the stove. The heated blast finally leaves the stove by the valve B, to the hot-blast main, and it has then an average temperature of 1400° F. (738° C.) to 1500° F. (815° C.). One stove is alternately heated up by the combustion of the waste gases, and is then employed in giving up its heat to the blast forced through it, and if these reversals or changes are made at sufficiently small intervals to prevent the hotter end of the stove from falling below redness, it is assured that the gases always ignite immediately they enter the stove, and the temperature of the blast is kept more regular.

The Whitwell stoves are provided with doors, F (Fig. 59), at the top, through which scrapers can be introduced for raking and cleaning out the dust from the walls; the dust, etc., so collected on the floor of the stove being afterwards removed through the six side cleaning-doors E (Fig. 60), at the bottom of the stoves. This operation of cleaning occupies from eight to ten hours, but can be effected whilst the stove is still at a red heat, and requires repeating every two or three months.

The Massick and Crookes stove resembles that of Whitwell, but is claimed to afford greater facilities for cleaning. The combustion chamber is in the centre, the heating chambers being around it, the gas traverses the stove three times.

The Ford and Moncur Stove.—This (see Figs. 61 and 62) is now one of the most popular stoves, and is largely replacing the earlier forms. It differs from the others in several respects. The combustion chamber extends right across the stove, thus dividing it into two heating chambers, one on each side, each of these being again divided into two by a cross wall, so that there are four distinct heating chambers, and each of these is provided with its own set of valves, and any one can be "cut out" if necessary.

The heating chambers are divided into narrow passages by a series of parallel walls, and these are crossed by a large number of lozenge-shaped bricks placed with the sharp edges upwards and arranged so as to "break joint." A chequer work is thus formed, which is very strong, offers a large heating surface, and does not accumulate dust. Across the upper part of the combustion chamber arches are built which carry walls dividing it into passages so as to help the absorption of heat. The gas and air enter the combustion chamber where they are burned, and the products spread over the heat-

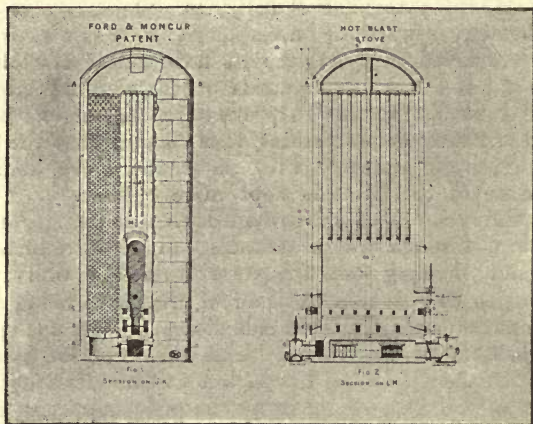


Fig. 61.

Fig. 62.

Figs. 61 and 62.—Ford and Moncur Stove, Sections at Right Angles to and through the Combustion Chamber.

ing chambers and descend to the flue. The heating surface is very large, a stove 72 ft. high having about 64,000 sq. ft.

Valves.—The stoves must be provided with efficient valves. The cold air valve usually opens to the outer air; it is provided with a cover, by which the amount of air admitted can be regulated. The cold blast valve may be an ordinary disc valve, but the hot blast valve, being subject to great heat, is always made hollow, and is kept cool by the circulation of water or air.

Cleaning Stoves.—A considerable quantity of dust is

carried over into the stoves, and the air current, being slower than in the mains, a good deal settles out, and it is very important to allow no places for the lodgment of this dust. Dust-catchers keep back some of the dust, but not by any means all. Cleaning doors are provided, which can be instantaneously opened. The cold blast is sent in, all the valves are closed, and the air, expanding by the heat, exerts considerable pressure; then the doors are suddenly opened, and the dust is blown out.

In the older forms of stove, where the dust found ready lodgment on the bricks, it was common to explode a small charge of powder or fire a gun into the stove to shake down the dust. Often cleaning holes are provided in the roof by which wire brushes can be passed down the passages; and sometimes the stoves are built on columns with cleaning doors at the bottom, so that brushes can be put upward, this being always done when the stove has been for some time on air, so that the bottom is comparatively cool.

Size and Number of Stoves.—Stoves are now built up to 80 ft. high and 25 ft. in diameter. In this country, usually all the stoves are in connection with the same main, so that all the air supplied to the furnaces is at the same temperature. As the stoves are worked in pairs, at least two must be used, and in general there will be some multiple of two, unless, as is often the case, an additional one is provided to allow for repairs. In general, two stoves should be provided for each furnace, but in many works the number is less, whilst in some recent works four stoves are provided per furnace. In the best modern practice each furnace has its own pair of stoves, an additional one being provided to allow of repairs.

The amount of heating surface required varies with the temperature of the blast. For a large output and a very hot blast Mr. Stevenson gives 444 sq. ft. of heating surface for each ton of iron produced in twenty-four hours.

Equalising Temperature of the Blast.—With fire-brick stoves, which are usually reversed every hour, there must be a variation in temperature, the blast being hottest when the stove is first put on, and falling gradually. With a blast at 1,300° or 1,400° F. (700°–760° C.) the fall of temperature during the run will be about 200° F. (110° C.). This can, to some extent, be prevented, the temperature being reduced to

the lower point by admitting a regulated and diminishing quantity of cold air to the hot blast main. This is, however, troublesome. Messrs. Gjers and Harrison have recently suggested the use of an "equaliser," which is simply a large hot blast stove, so placed that the hot air from the stoves on its way to the furnace passes through it. Thus the variation in the blast temperature is reduced to a very small amount.

Use of Dry Air.—For a large output it is essential that the temperature at the bosh of the furnace should be kept as high as possible. If the air blown into the furnace contains—as it always does—water, this is decomposed thus : $\text{H}_2\text{O} + \text{C} = \text{CO} + 2\text{H}$, yielding hydrogen and carbon monoxide. The carbon burning to carbon monoxide will evolve the same amount of heat as if it were burnt by air ; but each 9 lb. of water decomposed, liberating 1 lb. of hydrogen, will absorb 29,000 units of heat. This can only be prevented by using dry air. The air is, of course, not dried by heating, the term "dry" commonly applied to hot air not meaning that it is dry in the true sense of being free from moisture, but merely that it can take up a larger quantity, and therefore seems dry. The only way to dry the air is to cool it, so that the water which it holds is precipitated in the solid form. Mr. Gayley has suggested that the air should be dried before being passed to the hot blast stoves. He passes the air through refrigerating chambers consisting of iron pipes through which brine cooled below 0°C . is made to circulate so that the moisture in the air is precipitated. Not only is the quantity of moisture in the air considerable, but it is constantly varying, and in the case of Pittsburg Mr. Gayley has calculated that for a furnace using 40,000 cub. ft. of air per minute, from 73 to 237 gallons of water are carried into the furnace per minute, according to the condition of the air. The use of dry air, he contends, increases and equalises the output, and reduces the consumption of fuel. Against this has to be set the cost of the refrigerating plant, and whether the method will be profitable remains to be proved.

Temperature of the Blast.—The blast is now generally used at a temperature of about $1,400^\circ \text{F}$. to $1,500^\circ \text{F}$. (760°C . to 815°C .). The temperature should always be taken and recorded by a pyrometer placed in the hot blast main as near as possible to the furnace.

CHAPTER XI.

WORKING THE BLAST FURNACE.

CHARCOAL burns very readily, and owing to its being very porous gives a very high temperature at the tuyeres. It is so easily crushed that only small furnaces can be used. Charcoal, being free from sulphur, produces a superior pig-iron; but, owing to its cost, furnaces employing it are almost extinct. Even in Sweden, charcoal has been superseded by coke. From 21 cwts. to 22 cwts. of charcoal are required per ton of pig produced.

Coke is the chief fuel employed in iron smelting, and in selecting the best coke, regard should be paid to its freedom from ash and its power to resist a crushing pressure. A hard coke, yielding but a small proportion of ash matter, is preferred. The hard, compact coke employed in the Cleveland district contains from 4 per cent. to 10 per cent. of ash, and from 0.25 per cent. to 1.0 per cent. of sulphur; and an average of from 20 cwts. to 22 cwts. of it is consumed in the production of one ton of No. 3 grey foundry pig from Cleveland ironstone, yielding, after calcination, about 46 per cent. of metallic iron; and about $\frac{1}{2}$ cwt. under or above these figures is required respectively for the production of a number under or above No. 3 pig in quality. Thus, if 20 cwts. of coke be required for the production of No. 3 pig-iron, then $20\frac{1}{2}$ cwts. will be necessary for the production of one ton of No. 2.

The coke may be made either in Beehive or recovery ovens. At one time there was a prejudice against the latter, but that is now dying out, and most of the large works recover the by-products in the manufacture of the coke.

Coal is only used in localities where suitable coals occur. It must be of the non-caking variety, as free as possible from sulphur, and should afford but a small percentage of ash;

Caking coal has a tendency to collect into lumps, and so to obstruct the passage of the gases.

Raw coal is used only in Scotland, Staffordshire, and a few other localities, and except in Scotland (and sometimes even there) it is usually mixed with coke. The coal used is of the kind called splint coal, a non-caking coal burning with a long flame. It yields only from 50 to 65 per cent. of coke, and this coke is soft and friable. The volatile matter is expelled near the top of the furnace, so that it is only the fixed carbon of the coke which is available for combustion, and therefore a larger quantity of coal than of coke is required for the production of the same weight of iron. In Scotland about 32 cwts. to 36 cwts. of coal are used for each ton of iron produced. Owing to the coke yielded by splint coals being very friable, the furnaces used are always of small size, an actual working depth of 45 ft. to 50 ft. being the greatest that can be used satisfactorily, or somewhat more if a mixture of coal and coke be used.

Anthracite is a dense coal containing very little volatile matter. It is not porous, and so presents only a small surface to combustion, and tends to crumble to powder under pressure when hot. A high blast pressure is therefore required when it is used. Anthracite is now rarely used except mixed with coke.

The following table will give an idea of the composition of the various fuels :—

	A	B	C	D	E	F
Volatile Matter .	—	—	—	·460	42·30	42·05
Fixed Matter—i.e.						
Coke . . .	100·00	100·00	100·00	99·540	57·70	57·95
Fixed Carbon . . .	97·00	87·57	90·31	89·576	54·90	54·00
Ash	3·00	10·15	8·45	9·113	2·80	3·95
Sulphur	—	1·73	1·25	·821	·88	1·15
Moisture	—	·55	—	·210	7·1	8·10

A.—Charcoal. B.—Yorkshire Coke. C.—Scotch Coke. D.—Connells-ville Coke. E.—Govan Splint Coal. F.—Russel Splint Coal.

As already remarked, the quantity of air required is about 6 tons for each ton of carbon consumed, so that it really forms the largest portion of the income of the furnace.

FURNACE CHARGES.

The proportions of the various materials to be charged into the furnace must be carefully determined, and this can only be done if the composition of the material being used is exactly known, and therefore the chemical laboratory is a very important part of the equipment of a modern works working under the best conditions. In the earlier works, where ore of only one quality, usually obtained from one mine, was used, analysis was of less importance, but now with materials of very varying composition drawn from all parts of the world, accurate analysis is essential.

The various cargoes of ore as they come in will be sampled and analysed, and of course kept in separate ore bins. The calculations to be made will be, in general, three :—

(1) To ascertain the amount of flux (limestone) to be added to the charge.

(2) To ascertain the amount and composition of the iron which will be obtained.

(3) To ascertain the proportions in which ores must be mixed to give an iron of definite composition.

In order that these calculations may be made, it is necessary to know :—

(1) The composition of the ore.

(2) The amount and composition of the ash of the fuel being used.

(3) The composition of the limestone available as a flux.

(4) The type of silicate which it is intended the slag shall be.

In order to illustrate the method of making the calculations the simplest plan will be to take an example. Assume that the ore to be used has the following composition :—

Ferric oxide . . .	70	per cent.	= Iron . . .	49.00	per cent.
Manganese oxide . . .	2	„	= Manganese	1.55	„
Alumina	4	„			
Lime	2	„			
Magnesia	1	„			
Silica	12	„			
Sulphur	1	„			
Phosphoric anhydride	1	„	= Phosphorus	.43	„
Water	7	„			

100

The coke contains 1 per cent. of sulphur, and yields 10 per cent. of ash, which has the composition :—

Silica	.	.	.	.	.	50.0 per cent.
Alumina	.	.	.	.	.	45.0 „
Lime	.	.	.	.	.	2.5 „
Magnesia	.	.	.	.	.	2.5 „
						<hr/> 100.0 <hr/>

The available limestone contains :—

Calcium carbonate	.	.	.	.	.	97 per cent.
Silica	.	.	.	.	.	3 „
						<hr/> 100 <hr/>

A. The Amount and Composition of the Iron that will be Obtained.—The furnace is being run for a No. 1 iron to contain about 3.5 per cent. of carbon and 2.5 per cent. of silicon. It may be assumed that other impurities will be about 2 per cent. This can be judged roughly from the analysis of the ore, and great accuracy is not necessary, as the iron cannot be made exactly to the required composition. The pig iron will then contain 92 per cent. of iron.

The ore yields 49 per cent. of pure iron, but the amount of pig iron will be larger in the proportion of 92 : 100—that is,

$$\frac{49 \times 100}{92} = 53.25, \text{ say } 53.2 \text{ per cent.}, \text{ or 1 ton will yield about}$$

10.7 cwt. of pig iron. The whole of the phosphorus and one half of the manganese will pass into the iron. The ore contains .43 per cent. of phosphorus. That is, there will be .43 lb. of phosphorus in the 52.7 lb. of pig iron, so that the com-

position will be $\frac{43 \times 100}{53.2} = .808$, say .81 per cent. The ore

contains 1.55 per cent. of manganese, of which one-half will probably go into the iron; the percentage will therefore be

$$\frac{.77 \times 100}{53.25} = 1.45, \text{ say } 1.5 \text{ per cent. The pig iron will there-}$$

fore contain :—

Iron	91·7 per cent.
Carbon	3·5 „
Silicon	2·5 „
Manganese	1·5 „
Phosphorus	·8 „
	<hr/> 100·0

These figures are, of course, only approximate, and the iron contains only 91·7 instead of the 92 per cent. of iron assumed.

It is obvious that this method of calculation would not be applicable if there were a large quantity of phosphorus or manganese present, unless the percentage of iron likely to be present be judged, as it easily can be, from the analysis of the ore.

Suppose the ore had contained 3 per cent. of phosphorus. Taking in all other respects the same figures as before, it is seen that the iron and phosphorus together will amount to about 93 per cent. of the weight of the pig-iron, so that the amount of iron obtained for each 100 lbs. of ore will be

$\frac{(49 + 3)}{93} \times 100 = 55·9$, say 56 lbs. In this 56 lbs. there will be 3 lbs. of phosphorus, so that the percentage will be $\frac{3 \times 100}{56} = 5·36$, say 5·4%. As the total amount of pig-iron produced per ton of ore is slightly larger, the percentage of manganese will be slightly less by

$$\frac{·77 \times 100}{56} = 1·19, \text{ say } 1·2\%,$$

and the composition of the iron will be :—

Iron	87·5 per cent.
Carbon	3·5 „
Silicon	2·5 „
Manganese	1·1 „
Phosphorus	·4 „
	<hr/> 100·0

Calculation of the Charge.—In running for a No. 1 iron from a hæmatite ore it may be assumed that each ton of iron produced will require 22 cwts. of coke, or 100 lbs. of iron will

require 110 lbs. of coke, so that 53·2 lbs. of iron or 100 lbs. of ore will require 58·5 lbs.; so that the charge will consist of 100 lbs. of ore to 58·5 lbs. of coke.

The most important calculation is that for the quantity of limestone which has to be added for fluxing. In order to ascertain this, the type of slag to be produced must be determined on. This may be stated in several ways, and the calculation will be slightly different, according to the basis adopted. It may be decided to make a slag containing a definite percentage of silica or one of a definite type. In the former case the type will vary with the nature of the bases, since different bases combine with different proportions of silica, and in the latter case the percentage of silica will vary with the bases present. In all respects the type system is the best, though the silica percentage is the most generally used.

Assume the slag to be of the mono-silicate type—that is, such as 2CaOSiO_2 , containing two molecules of lime to one of silica, which, if no base but lime were present, would contain 34·9 per cent. of silica and 65·1 per cent. of lime.

It is quite obvious that if two silicates of the same type be taken, but containing different bases, as, for instance, 2CaOSiO_2 and 2MgOSiO_2 , the proportions of silica to base will be different, and that it will be easy in the case of any given base to calculate a factor which by simple multiplication will give the amount of silica that will be required to combine with any base to form a silicate of the type required. These factors are used in what follows, and the method of calculating them is fully explained in the appendix.

The bases to be fluxed away are manganese oxide (one-half of that present), lime, magnesia, and alumina, which in these calculations is regarded as being a base:—

<i>Base.</i>	<i>Percentage.</i>	<i>Factor.*</i>	<i>Amount of Silica Required.</i>
Manganese oxide	1	× ·423	·423
Alumina . .	4	× ·882	3·528
Lime . .	2	× ·536	1·072
Magnesia . .	1	× ·750	·750
Total	.	.	5·773

* For table of factors see p. 248.

That is, the bases in 100 lbs. of ore will flux 5.773 lbs. of silica, leaving $12 - 5.773 = 6.227$ to be fluxed by added lime. The percentage composition of the coke ash has been given, but as each 100 lbs. of ore requires 58.5 lbs. of coke, and the coke contains 10 per cent. of ash, there will only be 5.8 lbs. of ash per 100 lbs. of ore. Or:—

Silica	$\frac{50 \times 5.8}{100}$	= 2.90 lbs.
Alumina	$\frac{45 \times 5.8}{100}$	= 2.61 „
Lime	$\frac{2.5 \times 5.8}{100}$	= .146 „
Magnesia	$\frac{2.5 \times 5.8}{100}$	= .146 „

The bases can now be multiplied by the factors as before:—

Alumina . . .	2.61	×	.882	=	2.30
Lime . . .	.146	×	.536	=	.08
Magnesia . . .	.146	×	.750	=	.11
					<hr/> 2.49 lbs.

so that the bases present will combine with 2.49 of the 2.90 lbs. of silica present, leaving $2.90 - 2.49 = .41$ lb. to be fluxed by the added lime.

The total silica to be fluxed away is therefore $6.23 + .41 = 6.64$ lbs., less the silica which goes into the pig-iron as silicon: viz. $(.025 \times 53.2) \times 60 \div 28 = 2.22$ lbs.

The limestone contains:—

Lime	54.3	per cent.
Carbon dioxide	42.7	„
Silica	3.0	„
	<hr/> 100.0	

The carbon dioxide will, of course, be expelled. The silica present will combine with $3 \times 1.86 = 5.58$ parts of lime to form a mono-silicate, so that the available lime is $54.3 - 5.58 = 48.72$ lbs. for each 100 lbs. of limestone.

The amount of silica to be fluxed away is 4.42 lbs., and this will require $4.42 \times 1.86 = 8.74$ lbs. of lime, or $\frac{8.74 \times 100}{48.72} = 16.88$ lbs. of limestone.

There is still one item to be taken into account. Both the ore and the coke contain sulphur, and lime must be provided to carry this into the slag as calcium sulphide (CaS).

The amount of sulphur is :—

In 100 lbs. of ore	.	.	.	1.000 lb.
In 4.58 lbs. of coke	.	.	.	.058 „
				<hr/> 1.058 „

This will require $1.058 \times 1.75 = 1.85$ lbs. of lime, or
 $\frac{1.85 \times 100}{48.72} = 3.97$, say 4 lbs. of limestone. The charge will therefore be :—

Ore	.	.	.	100.0 lbs. or	20 cwts.
Coke	.	.	.	58.5 „	= 11.7, say 12 „
Limestone	.	.	.	20.8 „	= 5.0, „ 5 „

a little additional lime being usually added to keep the slag basic.

Calculations can be made in a similar way if a slag with a given percentage of silica is aimed at.

The composition of the slag can be calculated by collecting together the weights of the various constituents from the three sources.

Ore Mixing.—It is often necessary to ascertain the proportions in which ores should be mixed so as to obtain iron of a given composition. The proportions are often judged by inspection of the analyses, the mixture thus made being considered as a single ore, and the calculations made exactly as described.

Only one case will be considered. Two ores are in stock—an ore A, which contains 60 per cent. of iron and .08 per cent. of phosphorus; and an ore B, which contains 45 per cent. of iron and 1.6 per cent. phosphorus—and it is required to make an iron containing 1.0 per cent. phosphorus. It is quite obvious that if A alone were used the iron would be low in phosphorus, and if B alone were used it would be too high.

It may be assumed that the pig-iron will contain about 92 per cent. of iron, and this must therefore be the basis of the calculation. In A: for each 92 parts of iron there is
 $\frac{92 \times .08}{60} = .12$ parts of phosphorus. In B: for each

92 parts of iron there is $\frac{92 \times 1.6}{45} = 3.27$ parts of phosphorus. Taking A as the basis, we have for each 92 parts of iron :—

P Present. P Required. Deficiency. Excess.

A	.12	1	.88	—
B	3.27	1	—	2.27

so that the ores must be mixed so as to yield iron in the proportion $\frac{2.27}{.88} = 2.58$. That is, for each 1 part of iron yielded by B, 2.58 parts must be yielded by A, thus :—

P Present. P Required. Deficiency. Excess.

A	.12 × 2.58 = .309	2.58	2.271	—
B	3.27	1.00	—	2.271

To yield 100 parts of iron 222 parts of B would be required, and to yield 258 parts of iron 430 parts of A would be required, so that the ores would be mixed in the proportions of 222 to 430 or 100 B to 194 A, or probably, in round numbers, 20 cwts. B to 39 cwts. A would give the composition required. Similar calculations can be made for any other element, and of course more than two ores may be mixed.

Economy of a Furnace.—The economy with which a furnace is working is measured by the amount of fuel consumed for each ton of iron produced, and this will depend on the ratio between the heat utilised and the heat lost.

It has been found that increase in the size of the furnace has led to increased economy; that is, to a reduction in the amount of fuel used.

Increase in height tends to economy because the gases are more perfectly cooled, and therefore carry away less heat, and also because the ore is longer in the zone of reduction, and therefore is more perfectly reduced by the carbon monoxide; but a point is reached, varying with the conditions of working, when increased height no longer produces economy, the gases not being further cooled. This is partly, at least, due to the fact that the reaction by which the iron oxide is decomposed evolves heat, and as this takes place near the top of the furnace, it prevents complete cooling of the gases. In British working, with hard coke as fuel, the height of the most economical furnace is about 90 ft. In Scotland, where coal is used, the furnaces are rarely over 60 ft. in height.

Increase in the diameter of a furnace has a similar result, as the wider the furnace the more slowly the gas current passes upward. A limit is put to the diameter of the hearth by the blowing power available, and the furnace must not be so wide in any part that there is not a regular upward flow of the gas through the materials in all parts. That therefore fixes a limit to the diameter of the furnace.

These conditions are to be taken as being generally true, since much depends on the conditions under which the furnace is being worked. In general, the consumption of fuel may be taken as being :—

British coke-fed furnaces working on Cleveland ores,

21 cwts. to 22 cwts. per ton of iron.

American coke-fed furnaces working on hæmatite ores,

18 cwts. to 20 cwts. per ton of iron.

Scotch coal-fed furnaces working on hæmatite ores,

30 cwts. to 36 cwts. of splint coal per ton of iron.

Output of Furnaces.—The output which can be obtained from a furnace varies with the conditions. Obviously, the larger the output that can be obtained the better, provided that there is no decrease in economy and the furnace is not too rapidly worn out.

At the two extremes may be put Scotch practice with raw coal, the average output being about 300 tons per week, and American practice, as it is called, though carried out at many British works, with an output up to 2,000 tons per week ; whilst the old Cleveland practice, with coke as fuel and an output of 800 tons or so per week, stands in between.

The output or, what comes to the same thing, the rate of driving depends mainly on the amount of air supplied to the furnace. There is always plenty of fuel in the furnace. The more rapidly this burns away, the more rapidly the charge will descend, the larger will be the amount of iron obtained. Hence in new furnaces intended for rapid driving the number of tuyeres is increased to eight or ten, and these are made of large diameter. It must be remembered that the area increases as the square of the diameter, so that a 7-in. tuyere will pass four times as much air as a $3\frac{1}{2}$ -in. tuyere—indeed, rather more, owing to lessened friction—at the same pressure. The blast is also supplied at a higher pressure so as to get a more rapid air current.

It has already been pointed out that for very rapid working, mechanical devices must be used for charging and removing the metal; also that, owing to the rapid combustion, the temperature becomes very high and the bosh of the furnace must be continually cooled. Whether rapid driving will be advantageous or not will depend on circumstances. In Scotch furnaces, where the fuel is coal from which the volatile matter has to be expelled and the ores used are hard and dense, rapid driving has not been found to be possible. On the other hand, in America, with soft, porous hæmatites, it has been found to be quite satisfactory. For every condition of fuel and ore there will be a maximum rate of descent of the charge, beyond which any increase will cease to be economical.

With rapid working the character of the iron is usually modified. It comes down so rapidly that it is not left long in contact with the other materials of the charge; therefore less silicon is reduced, so that American irons, or those made in this country in furnaces driven very rapidly, are usually low in silicon, often not containing more than 1 to 1·5 per cent. The more rapid the driving the more quickly will the furnace-lining wear out. Scotch furnaces often remain in blast twenty years or more, whilst the furnaces that are driven hard require re-lining every two or three years. The whole question of rate of driving is more a question of economy than of scientific principle, and ironmasters soon find out what is the most economical rate of driving under the conditions of their works.

The Hot Blast.—The introduction of the hot blast by Neilson in 1828 led to a great saving in fuel. The effect produced at the Clyde iron works where the hot blast was introduced will be seen from the following figures:—

	WEEKLY MAKE PER FURNACE.		COAL USED PER TON.		
	tons	cwt.	tons	cwt.	lb.
1829, January to August, Coke and Cold Air	36	18	8	19	1
1830, January to August, Coke and Air at 300°	54	1	5	3	1
1833, January to August, Coke and Air at 600°	61	1	2	5	1

To-day, with the blast at $1,400^{\circ}$ F. and raw coal as fuel, the weekly make is about 300 tons, and the consumption of fuel about 32 cwt. The changes shown from 1829 to 1833 were entirely due to the use of the hot blast, since no other changes were made in the working, and in each case the coal consumption includes that used in heating the air, since it was not till later that attempts were made to utilise the waste gas for heating purposes. It may also be noted that the coal was coked—raw coal not being used till after 1831; and the wasteful method of coking led to considerable waste of fuel; but this would be the same in each of the three years. The furnaces also were very small. For these reasons, whilst the introduction of the hot blast always led to saving of fuel, in no other district was the saving so large as in Scotland.

The tendency of late has been to use the blast as hot as possible, $1,400^{\circ}$ to $1,450^{\circ}$ F. being the usual temperature; and each increase in the temperature of the blast has led to increased saving in fuel, but in a constantly diminishing ratio.

The reasons for the saving, leaving out of account the fact that the heat is now obtained from the waste gases, and therefore that some of the heat is carried back into the furnace, seem to be:—

(1) That the quantity of gas passing through the furnace is considerably diminished, and therefore that it can be more effectively cooled.

(2) One essential for good working is that the actual zone of fusion opposite the tuyeres should be very hot, and there is no advantage in extending this zone upwards. When air is blown into the furnace, by the combustion which takes place it becomes intensely heated, and therefore expands, and this expansion absorbs heat and this tends to cool the furnace. It is obvious that the greater the rise of temperature the greater will be the absorption of heat and consequent cooling, and therefore the fusion zone will be higher.

To send in the same weight of air the volume is much greater for hot than for cold air, and therefore all pipes must be made larger as the temperature of the blast is increased. The early ironmasters noticed that the output was larger in winter than in summer, this being due to the air being cooler, and therefore denser, so that more was sent in, and also to

it being drier ; and some of them had the idea, therefore, that it would be better to cool the air rather than heat it.

Kind of Iron Produced.—The variety of iron produced in the furnace is not absolutely under control, as the furnace will sometimes run an iron not desired, but, in general, iron of required quality can be made. The output as to quality and quantity can be controlled by varying the proportions of ore flux and fuel in the charge and by varying the temperature and quantity of the blast.

When the proportion of fuel to the ore is small, the furnace is said to have a heavy burden. When it is large it has a light burden. For the production of irons high in silicon, such as No. 1, the furnace must be worked at a high temperature, and therefore the proportion of fuel must be large or the burden light. The charge must also descend at such a rate as to allow of the silicon being taken up. With very rapid driving, as already remarked, the iron tends to be low in silicon. The quantity of lime must be only sufficient to form a good slag ; if the quantity is insufficient, a siliceous slag may be formed, and too much silicon may pass into the iron. The obvious remedy is to increase the amount of limestone in the charge.

When it is required to make an iron very high in silicon, the quantity of fuel is largely increased and the quantity of lime is reduced. By these means a very high temperature is obtained, and very refractory siliceous slag, which usually contains some iron, is produced.

Manganese is difficult to reduce, and the oxide combines readily with silica. When it is required to pass manganese into the iron—the manganese, of course, being in the ore—a large quantity of fuel must be used, so as to produce a high temperature and at the same time a considerable quantity of lime must be added to keep the slag basic.

When the furnace is worked with a heavy burden, the temperature is low, but little silicon is reduced, and the iron tends to be white and at the same time to take up sulphur. The more basic the slag the less sulphur will be taken up by the iron.

By carefully adjusting the conditions, the skilful blast manager can usually produce iron of any quality which he requires, and the demands of the trade to-day require the

production of iron of very varying quality for different purposes.

The fusibility of the slag may have considerable influence on the quality of the iron, and should be adjusted to the temperature of the furnace. A very fusible slag will melt high up the furnace and run down into the hearth, whilst a less fusible one will remain mingled with the charge until it is much further down. Once a slag melts and runs down it is out of the sphere of action. When iron passes into the slag it is probably not from unreduced iron oxide, since reduction should be complete at a temperature below that at which the combination of the oxide of iron and silica can take place, but is probably mainly produced from iron oxidised by the carbon monoxide; and this action, according to Sir Lowthian Bell, becomes less energetic as the temperature rises. When a furnace is working at a low temperature, and with the production of a very fusible slag, iron may be readily taken up, and may not be reduced on running through the charge. On the other hand, if the slag is not so fusible, it will reach a temperature at which oxide of iron is not formed or cannot exist before it melts. Whilst the slag is in a partly unfused condition it can still be acted on by the agents around. Highly siliceous slags are difficultly fusible, and therefore retain the silica in a condition in which it can be reduced by the carbon.

Accidents.—Scaffolds and slips have already been mentioned. Explosions sometimes occur, at the hearth from the bursting of a water tuyere, and at the top of the furnace from causes of which at present little is known. It is not likely to be leakage of air, since there is always a pressure in the furnace, though the slip of a scaffold might cause a partial vacuum, and this perhaps might draw in air enough to cause an explosion. Wet ore, if suddenly let down by a slip into a hot part of the furnace, might suddenly evolve enough steam to produce an explosion. Explosions at the furnace top are not common, but are sometimes disastrous.

CHAPTER XII.

THE BY-PRODUCTS.

As the blast furnace is worked for the production of iron, anything else that may be obtained, whether of value or not, must be a by-product. For each ton of iron produced there will be, under ordinary circumstances :—

Slag from .5 to 2 tons.

Gases about 8 tons.

These gases, in the case of coal-fed furnaces, carrying a considerable quantity of tar and ammonia.

It becomes, therefore, a matter of very considerable importance to utilise, if it be possible, this large quantity of material.

Slag.—The amount of slag produced in Middlesborough and in Scotland is about 1.5 tons for each ton of iron made. In the hæmatite districts, where the ores are much richer, the amount is about one ton, or sometimes less.

The disposal of the slag is very troublesome and costly, and many attempts have been made to utilise it in various ways.

Ballast.—The slag may be broken up and used as ballast for railways or for road making. A considerable quantity of slag is used for this purpose. It must not be too high in lime or would crumble to pieces under the influence of air and moisture.

Cement.—A very good cement can be made from a suitable slag, one which contains a fair proportion of alumina and not more than about 3 per cent. of magnesia. The hydraulic power of cement seems to be due to the presence of basic silicates and aluminates of lime which dissolve momentarily in water, then absorb water and crystallise. The calcium silicate having the greatest setting power is said to have the formula $3\text{CaO}, \text{SiO}_2$. If the constituents be fused in this proportion a fusible slag is produced, but as it solidifies it breaks up, probably forming $2\text{CaO}, \text{SiO}_2$ and free lime ;

therefore slags rich in lime disintegrate on exposure to the air owing to the slaking of the lime. The basic silicate can be formed, however, by heating the constituents to a temperature somewhat below the fusing point of this silicate.

The slag is granulated by being run into water, dried, and crushed to an impalpable powder. The requisite amount of lime is crushed and the two constituents are thoroughly mixed. The mixture is then calcined in a suitable kiln till particles adhere, forming "clinker," the size of the lumps of "clinker" varying with the form of the kiln in which the operation takes place. The "clinker" is ground, and the ground material is a cement in all respects resembling Portland cement. It may be used alone, or very often is mixed with Portland cement.

Bricks.—At one time building bricks were made by mixing pulverised slag with cement, pressing under hydraulic pressure, and allowing it to harden in the air. From some varieties of slag, bricks suitable for paving or building may be made by casting the slag in suitable moulds.

Paving Blocks.—These are now made on a large scale. The slag is crushed, mixed with a quantity of Portland cement, and the slabs are compressed under hydraulic pressure of about 500 lb. per square inch. Such blocks are very durable.

Slag wool (silicate cotton) is largely used as a non-conducting material. A cubic foot of slag yields about 12 cub. ft. of wool, and the entangled air makes it a good non-conductor. The wool is made by blowing a stream of air or steam across a stream of molten slag, and subsequently separating the globules of fused slag.

All these uses, however, account for but a small proportion of the slag actually produced. The bulk of it still accumulates in slag heaps.

Gas.—The gas, as already remarked, forms the largest proportion of the by-products, and from the large quantity of carbon-monoxide it contains it is always valuable as a fuel.

The gas is now used for heating the blast, the raising of steam, the direct driving of gas engines, and for other purposes. About 25 per cent. by volume of the gas is composed of combustible carbon-monoxide, and the heating power of the escaping gases per ton of metal produced in the Cleveland furnace is equal to that furnished by the

combustion of about $11\frac{1}{2}$ cwts. of coal. Blast furnace gas contains as carbon-dioxide and as carbon-monoxide, the whole of the carbon of the fuel and of limestone introduced into the furnace except that absorbed in the recarburisation of the reduced iron to the state of pig-iron, and the small amount escaping as cyanogen, in combination with potassium or sodium, as cyanide.

ANALYSES OF BLAST FURNACE GAS BY VOLUME.

	A	B	C	D	E
Nitrogen	55·35	57·22	57·06	62·34	57·79
Carbon-monoxide	25·97	24·65	28·61	24·20	23·51
Carbon-dioxide	7·77	12·01	11·39	8·77	12·88
Marsh gas (CH_4)	3·75	0·93	0·20	3·36	—
Olefiant gas (C_2H_4)	0·43	—	—	—	—
Hydrogen	6·73	5·19	2·74	1·33	5·82
	100·00	100·00	100·00	100·00	100·00

A.—Alfreton furnace working upon calcined argillaceous ironstone and raw coal, blast heated to 626°F. (320°C.) (Bunsen and Playfair). B.—French furnace working upon brown hæmatite, lime and charcoal (Ebelmen). C.—Seraing upon brown hæmatite, mill, cinder, lime and coke blast 212°F. (100°C.) (Ebelmen). D.—Charcoal furnace (Bunsen). E.—French furnace working upon hæmatite, lime flux and charcoal (Ebelmen).

The gases do not differ essentially in composition whether hot or cold blast is employed, or whether charcoal or coke is the fuel employed.

Nitrogen forms more than 50 per cent. and carbon-monoxide (CO) 25 per cent. or more of the total volume; and the higher the ratio of carbon-dioxide to carbon-monoxide, the greater is the economy in the consumption of fuel, though this ratio can never be greater than 1 : 2 under ordinary conditions; also the lower the temperature at which the gases escape from the furnace, the less is the heat carried away and lost. The ratio of oxygen to nitrogen in the gases is in excess of that in the atmosphere, as a considerable quantity is derived from the reduction of the oxides of iron in the iron ores, and is contained in the carbon-dioxide expelled from the limestone added as a flux; while the free hydrogen is derived from the decomposition of water vapour carried in by the blast.

When raw coal is used, the gases are necessarily richer in hydrogen and in hydrocarbons, since the coal gas, which consists mainly of these gases, mixes with the gases produced by the combustion of the coke, in this case also the gases carry over a quantity of tar and ammonia; but as these are condensed before the sample is analysed, the green (or unwashed) and the washed gases do not show any difference in composition.

The following analyses of gases from Scotch coal-fed furnaces will indicate their general character:—

	A	B	C
Nitrogen	59·27	56·50	55·86
Carbon-monoxide	27·51	27·40	27·20
Carbon-dioxide	6·15	6·60	6·60
Marsh Gas	3·02	2·64	2·68
Hydrogen	3·68	6·86	7·66
	<hr/> 99·63	<hr/> 100·00	<hr/> 100·00

A and B.—Unwashed. C.—Washed.

It is quite obvious that, considered as a source of heat, the gas from a coal-fed furnace is better than that from one that is coke-fed.

The current of waste-gas also carries over with it into the tubes and flues an amount of dust, containing silica, alumina, ferric oxide, lime, calcium sulphate and phosphate, with smaller proportions also of magnesia, manganese oxide, potash, soda; and if the ores contain zinc, then this dust will contain in addition zinc oxide. This dust accumulates slowly in the flues, and requires to be cleared away from time to time; or it is separated by washing arrangements connected with the top of the furnace.

In the case of a coal-fed furnace the tar would also accumulate. The dust in the one case and the tar in the other render the gas unsuitable for use in gas engines without some purification. In the case of coke-fed furnaces, all that is needed is a simple washing, but with coal-fed furnaces more elaborate processes are resorted to so as to recover the tar and ammonia, which are of considerable value.

Washing the Gas from the Coke-fed Furnaces.—The gas is passed through vessels in which water is kept in a violent state of agitation by means of dashers, so that the dust is washed out of the gas, and if necessary it is then passed through some filtering material to remove the last traces.

Recovery of Tar and Ammonia.—Ordinary Scotch splint coal contains about 1·4 per cent. of nitrogen, and when the coal is distilled in the blast furnace about 16 per cent. of this comes off in the form of ammonia. This is equal to about ·22 per cent. of nitrogen, given off as ammonia, or 4 to 5 lbs. of nitrogen, or 23·5 lbs. of ammonium sulphate per ton of coal consumed. This is, of course, a small amount, but when the

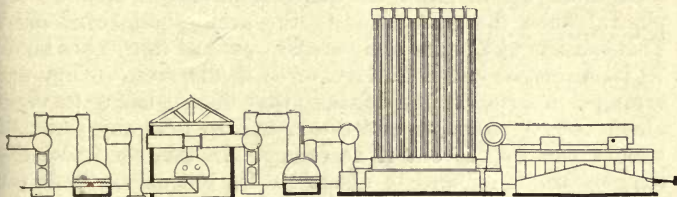


Fig. 63.—Gillespie By-product Plant, Section.

enormous amount of coal consumed is taken into account, it becomes of value.

The first plant erected to recover the tar and ammonia was that of Messrs. Alexander and M'Cosh at the Gartsherrie iron works, and the principle which they adopted of cooling the gas and then scrubbing or washing with water has been followed in all other plants since erected.

Three types of plant are in use. The one to be described is that of Messrs. Gillespie (Fig. 63), which has been erected at many works in Scotland, and in which the costly scrubbers used in the older systems are dispensed with.

The amount of gas to be dealt with is enormous. Each ton of coal will give about 120,000 cub. ft. of gas through which the small quantities of condensible products are distributed, and in order to separate these the gas must be thoroughly cooled and then treated with water. The Scotch furnaces are small, consuming about 75 tons of coal in twenty-four hours, so that there will be about 8,600,000 cub. ft.

of gas per day per furnace, or for a works with eight furnaces about 71,000,000 cub. ft. of gas per day. It is this enormous amount of gas that makes the problem of recovery so difficult.

The gas will leave the furnace at a temperature of about 300° C., or a little less, and will cool somewhat on its way to the condensing plant. It passes through a dust-catcher attached to the furnace, where some of the coarser dust settles, then by large mains to the condensing plant.

The gas is passed through a tar washer—a large iron vessel containing tar; this keeps back the dust, which would otherwise be carried over, and at the same time acts as a seal, so as to cut off the gas in the mains from that in the recovery plant. Then the gas passes to the atmospheric condenser. This consists of a series of about 200 vertical iron tubes 60 or 70 ft. in height and 2 ft. 6 in. or so in diameter. They are arranged in series on iron boxes so that the gas has to traverse about twenty tubes up and down, and so that any series of twenty can be cut out if necessary. In this condenser the temperature is reduced to about 60° C., but only a little tar separates; probably it is in such a fine state of division that it is carried forward mechanically. Then the gas is passed through the first washer. The washers are all alike, and consist of long iron boxes divided by screens, so arranged that owing to the large area the gas travels very slowly, and by passing under the screens it is broken up into innumerable, very minute bubbles which pass upward through the water.

The resistance to the passage of the gas is so great that the pressure in the blast furnace would not be sufficient to force it through the apparatus, so that it becomes necessary to use a blower of some kind. In the first forms of plant a Roots blower was used to draw the gas through the first washer and force it onward through the second, or in some cases second and third; but in the latest installations these are replaced by exhausters driven by Parsons turbines. If three washers are used fresh water is supplied to the third. This is then pumped into the second, and then into the first, so that the gas passes through clean water in the last washer. The water containing the tar and ammonia is run into large settling tanks, where the tar sinks to the

bottom, and thence the two can be drawn off separately for further treatment.

The products are :—

(1) **The Gas.**—This is now nearly free from tar and ammonia, and is passed on to the boilers and stoves. It still contains a minute trace of tar, and for use in gas engines needs some further treatment. It burns with a non-luminous flame, and of course its heating power is less than that of the green gas before washing, but still will be greater than that of gas from a coke-fed furnace. The gas is clean to use, and having been well cooled contains but little water.

(2) **The Tar.**—About 40 gallons (say 400 lbs.) of green tar is obtained for each ton of coal consumed. This is forced up into large stills, very like the common haystack boiler, and is heated till all the water is expelled, when about 5 lbs. of anhydrous tar will be left from each gallon of “green” tar. The boiled tar is then quickly heated, and breaks up into oils which pass over, and a residue of pitch which remains. The oil may be collected in one tank, but is usually fractioned, the receiver being changed during the process. Two fractions are thus obtained :—

(1) Lucigen oil, having a specific gravity of about .970.

(2) Creosote oil, having a specific gravity of about .989.

The Lucigen oil is largely used for burning in lucigen and other blast lamps, as a fuel, and for other purposes. The creosote oil contains phenols, and may be used as a disinfectant. One firm prepares from it a disinfectant which is sold under the name of neosote, and which is said to be equal in power to carbolic acid. The unfractioned oil is used as fuel for steam boilers and other purposes. The amount of oil obtainable varies, but may be taken as being roughly 40 per cent. of the tar, or say 6 to 6½ gallons per ton of coal consumed. The amount of oil varies also with the variety of pitch required : the softer the pitch the less oil will be distilled out, and in any case the distillation must be stopped when the pitch is liquid enough to flow from the still.

The demand for the pitch is considerable. It is used in the manufacture of fuel briquettes, for setting in road paving, and for many other purposes.

The tar is very different from that which is obtained in a gas works. It must be remembered that the tar

does not exist as such in the coal, but is produced by the process of destructive distillation, and consequently the nature of the product will depend on the conditions under which it is produced. The tar from the blast furnace contains little or no benzene, which is the source of aniline, and thence of the coal-tar colours; and it is, therefore, of much less value than coal tar. The reason for the difference is that in the blast furnace the distillation takes place at a very low temperature, for it is brought about at the top of the charge by the hot gases, the temperature of which, as already mentioned, is about 400° C.

(3) **Ammonia.**—The ammonia liquor contains the ammonia almost entirely in the free condition. It is pumped to the top of a series of stills, down which it falls, meeting an ascending current of steam. The ammonia is carried forward with the steam, passed into sulphuric acid, and crystallised; the crystals are fished or blown out of the saturator, dried in a centrifugal drier; and are then ready for the market. The yield varies according to the amount of nitrogen in the coal from 20 to 25 lbs. of sulphate per ton of coal. The amount may, no doubt, also vary with the way in which the nitrogen is combined in the coal so that it is impossible to say from an analysis of the coal exactly how much ammonia should be obtained. The 16 per cent. already mentioned is, however, a fair average. We may now, perhaps, sum up the value of the products obtainable. Taking as a basis the production of 1 ton of pig iron, the output will be about:—

Pig iron, value, one ton, say	.	.	£2	5	0
Ammonium sulphate, 24 lbs.	.	.	0	3	4
Pitch, 160 lbs.	.	.	0	1	8½
Oils, 15 gallons	.	.	0	1	10½
<hr/>					
			£2	11	11
<hr/>					

The value of the by-products is thus shown to be 6s. 11d. per ton of iron, or nearly one-sixth of the value of the iron itself.

The following figures have been published with reference

to an installation of the Gillespie plant for four furnaces making hæmatite pig-iron :—

Coal consumed.	.	2,000 tons per week.
Pig-iron produced	.	1,400 „ „ „
Pitch recovered	.	100 tons, value £120
Oil recovered	.	20,000 gallons, „ 125
Sulphate of ammonia	.	20½ tons, „ 225
<hr/>		
Total by-products	.	£470
<hr/>		

The wages and other costs of working the plant are put at £30, and the cost of acid at £20 10s., leaving a handsome balance for interest, depreciation, and profit. Recovery plant has been put up in two or three English works, but as at all these the fuel used is a mixture of coal and coke, the yield is considerably less than in Scotland. Every iron works in Scotland, with one exception, is now fitted with recovery plant. The cost of the plant is high, reaching £5,000 or £6,000 per furnace.

Accidental Products.—Various minor by-products are sometimes obtained. If the ores contain lead, this may be tapped out with the iron. If zinc is present, it will collect in the flue dust. As already mentioned, cyanides are always formed, but up to the present no method has been found for the profitable recovery of them.

CHAPTER XIII.

MALLEABLE- OR WROUGHT-IRON:

MALLEABLE-, wrought-, or bar-iron, under which names the same metallurgical product is known, was formerly described as iron in its lowest degree of carburisation; but now all attempts to frame a definition of malleable iron upon a chemical basis have been futile, since in its low percentage of carbon, comparative freedom from such impurities as silicon, sulphur, phosphorus, etc., occurring so largely in pig-iron, it is rivalled or even excelled by the Siemens and the Bessemer mild steels; but malleable-iron differs from these materials even when otherwise of the same chemical composition, in the fact that it always contains particles of intermixed slag and oxide. A definition based on mode of production could be framed, because the metal has not been fused, but formed by the welding together of pasty messes under pressure.

Bar-, wrought-, or malleable-iron has a dull-bluish or blackish-grey colour, varying somewhat with its previous mechanical treatment, as to hammering, rolling, etc. Its fracture after hammering or rolling is of a fibrous character in the softer varieties, but becomes granular or crystalline in the harder kinds. The higher qualities of bar-iron present when broken a certain silky, fibrous appearance, which under repeated and long-continued vibration again assumes a granular or crystalline structure. The fractured surfaces are, however, more or less deceptive, since specimens broken by progressively increasing stresses are invariably fibrous, whilst the same specimen if broken by a sudden blow will exhibit a crystalline fracture.

Wrought-iron is one of the most malleable, tenacious, and ductile of the metals, its malleability increasing with the temperature short of fusion, to which it is heated. Sheets have been exhibited at Paris $\frac{1}{70}$ th of an inch in thickness, and at Pittsburg, according to report, they have been produced $\frac{1}{15500}$ th of an inch in thickness. Malleable-iron is

soft, but is exceeded in this respect by pure iron, and it is not sensibly altered as regards softness by being heated to redness and suddenly cooled by plunging into water; but bars of iron are shortened by this treatment.

The melting point of wrought-iron is between 2,732° F. and 2,912° F. (1,500° C. and 1,600° C.) according to Pouillet; it is at 3,812° F. (2,100° C.) according to Scheerer. The melting point of pure iron is now usually taken as being 1,600° C., that of commercial iron varies with the degree of carburisation and its freedom from sulphur, silicon, phosphorus, manganese, for all these impurities tend to lower its fusing point. When heated to whiteness, but before fusion occurs, it passes through a soft, pasty condition, in which two clean surfaces can be welded together, while at a red heat it is possible to hammer or forge the metal into almost any form.

Malleable-iron contains carbon from mere traces up to 0.25 per cent., occasionally reaching 0.3 per cent.; the latter figures indicate a material decidedly steely in character. The specific gravity of malleable-iron varies between 7.3 and 7.9, average specimens being about 7.6 or 7.7; its linear expansion by heat is about .000111 to .000126 of its length for each increase of one degree Centigrade, in which respect it thus stands lower than most of the metals, as is also the case with its cubical expansion or increase of volume by heat. Its specific heat is given as .114 at 0° C.

ANALYSES OF BAR-, WROUGHT-, OR MALLEABLE-IRON.

	A	B	C	D	E
Carbon	trace	0.075	0.016	0.180	0.230
Silicon	0.170	0.114	0.122	0.019	0.014
Sulphur	0.028	0.032	0.104	0.014	0.190
Phosphorus ..	0.200	0.004	0.106	0.074	0.020
Manganese ..	0.140	trace	0.280	trace	0.110
Iron	99.115	99.733	99.372	99.704	—
	99.653	99.958	100.000	99.991	—

A.—K.B.W. Best bar-iron (Pattinson). B.—Swedish O O (Author). C.—Low Moor Armour plate (Tookey). D.—Round bar, W. R. 3 (Downar). E.—Armour plate (Percy).

Malleable-iron may be exposed indefinitely, at the ordinary temperatures, to the action of dry air or even oxygen, without

suffering oxidation; but in the presence also of the vapour of water, and especially, too, of carbonic anhydride, the metal is rapidly tarnished or rusted (see p. 40), the corrosion gradually extending throughout the mass, if time be given. When, however, the metal is heated to redness and exposed to the air, oxidation proceeds very rapidly with the production of a black oxide of iron or forge-scale, which scales off from the bar when it is struck by the hammer. Heated to whiteness, malleable-iron burns, throwing off scintillations from its surface, whilst the iron so heated in contact with the air becomes unweldable and friable, constituting what is known as burnt iron, a condition due to the presence of oxides of iron throughout the mass. Continued hammering of malleable-iron in the cold state induces a hard, brittle, and more or less crystalline condition in the metal.

Malleable-iron combines readily with carbon when heated in contact with charcoal, coal, carbonaceous matters, or cyanogen compounds to a temperature above redness, as is shown in the case of the manufacture of cement or blister steel, and also by the operation of case-hardening, where articles of malleable-iron are heated in contact with leather cuttings, or cyanogen compounds (potassic ferrocyanide). Solid and gaseous cyanides, and nearly all vapours and gases containing carbon, such as carbon-monoxide and the various hydrocarbon vapours, impart carbon to iron when the latter is exposed at a red-heat for a considerable time to their action; the carburisation proceeding from the surface towards the centre of the bar.

Red-shortness or unforgeability of malleable-iron at a red-heat usually is caused by the presence of sulphur, as small a quantity as 0.03 per cent. making the metal distinctly brittle; copper is said to have the same effect. Cold-shortness or brittleness at ordinary temperatures is induced by the presence of small proportions of phosphorus, antimony, tin, or arsenic; a cold-short metal may be quite malleable and ductile at or above a red-heat. Karsten observes that the presence up to 0.3 per cent. of phosphorus produces an increased hardness without affecting the tenacity of the iron, while with 0.5 per cent. of phosphorus there is a decrease in tenacity, and it becomes also cold-short, or incapable of being worked

in the cold state without cracking at the edges, although when hot such a metal can be either rolled or hammered out readily. With 0.75 per cent. of phosphorus the cold-shortness is very decided, as is also the loss of tenacity, while when the proportion of phosphorus attains to 1 per cent. the iron becomes exceedingly cold-short. Eggertz, however, states that 0.25 per cent. of phosphorus in malleable-iron renders it sensibly cold-short. Doubtless the influence of small quantities of phosphorus upon the working qualities of wrought-iron is affected by the amount of such other elements as silicon and carbon present. The late Mr. A. L. Holley, C.E., was of opinion that 0.2 per cent. of phosphorus is not injurious, but, on the contrary, improves the malleable-iron if it be accompanied by 0.15 per cent. of silicon and 0.03 per cent. of carbon.

Silicon induces hardness and brittleness in wrought-iron, 0.35 per cent. sufficing to render the iron cold-short and low in tensile strength, but it is rarely present in appreciable quantity, except in the form of silica as a constituent of the cinder mechanically distributed throughout wrought-iron.

Tin also hardens malleable-iron, but produces brittle, unweldable, and cold-short metal.

The tensile strength of malleable-iron ranges between 17 tons and 26 tons per square inch of section, the average being taken at from 22 tons to 24 tons, and elongation or stretching before fracture may be taken at 35 per cent. or 40 per cent. of its length, in a test-piece 2 in. long and of $\frac{1}{2}$ in. sectional area. Special qualities of Bowling and Lowmoor iron give a tensile strength of 27 tons per square inch, and a ductility or elongation represented by 38 per cent. in a test-piece 2 in. long, whilst best Staffordshire iron of 24 tons tensile strength has an elongation of 30 per cent. in a test-piece 2 in. long. In considering the percentage of elongation before fracture, it is necessary to note the length of the test-piece employed, for with a longer test-piece the percentage of elongation will appear proportionately reduced, since the greater part of the elongation is distributed over only a very short length of the test-piece; thus the elongation of Staffordshire iron, given as 30 per cent. above, would not exceed about 20 per cent. if the test-piece were of the now more usual length of 8 in., instead of the 2 in. quoted above.

The tensile strength of iron plates varies as much as 20 per cent. in the same plate, according to the test-piece is taken lengthwise—that is, in the direction of greatest longitudinal extension, and therefore of development of fibre during rolling—or is cut crosswise from the plate; a test-piece cut longitudinally may have a tensile strength of from 20 tons to 24 tons per square inch, but a piece cut crosswise will break with from 18 tons to 22 tons; and thus the Admiralty require in first-class B B plates that they shall have a tensile strength of 22 tons per square inch along the length of the plate, with 18 tons to the square inch in a test-piece cut crosswise of the plate, besides which certain forge tests are specified, and all plates are to be free from lamination and surface defects.

Under the microscope malleable-iron is seen to consist almost entirely of crystals of iron, Figs. 64 and 65. These are irregular in form, as they have interfered with one another during growth. The carbon is present as small detached masses of pearlite, and if the section be at right angles to the direction of rolling in addition, there are many black specks of intermixed slag and oxide. The more thoroughly the metal has been worked the more numerous, smaller, and more evenly distributed will these particles be. If the section be taken parallel to the direction of rolling, the iron is still seen to preserve its crystalline structure; but in place of the black specks there are long strings of slag or oxide. When the metal is rolled hot the metal crystals are not elongated, since at welding temperature they can rearrange themselves freely, but the particles of slag and oxide are drawn out, and thus produce the fibre. The fibre, therefore, is due to the breaking up of the structure by the presence of these threads of foreign matter, and that is why malleable iron is so much weaker across the grain than with it. The fibre is not a source of strength, except in so far that it shows that the iron has been well worked because mild steel, which has no fibre, is stronger than malleable-iron of the same composition.

Wire-drawing very materially increases the tensile strength of iron.

Upon the differences in mechanical treatment of hammering, piling, welding, and rolling which the puddled ball

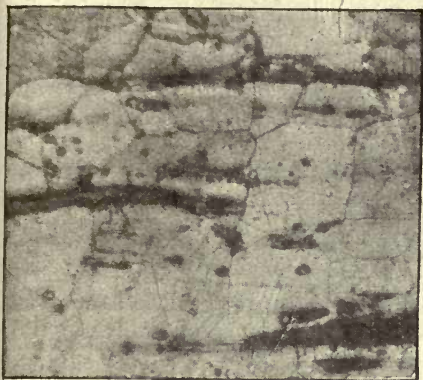


Fig. 64.—Micro Longitudinal Section of Malleable-iron.

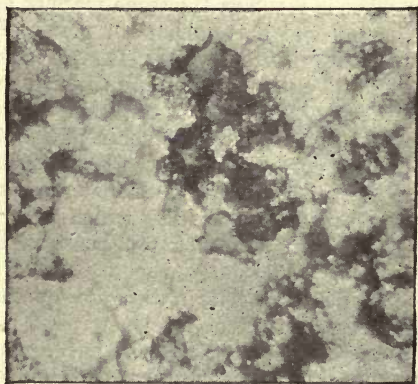


Fig. 65.—Micro Cross Section of Malleable-iron.

has received after withdrawal from the puddling furnace principally depends the commercial classification of malleable-iron into puddled bar No. 1, merchant bar No. 2, best or No. 3, best-best, and treble-best qualities or grades. Of these, puddled bar represents the long flat bars with a rather rough surface, which, whilst unfit for the smith's use, are used chiefly for cutting up and piling, as described later, for the production of No. 1 and the higher qualities of bar-iron. No. 1 is produced by the blooming of the puddled ball under the hammer or squeezer, and then passing the bloom so

produced without re-heating through the grooves of the roughing and finishing rolls for the production of the required section, which varies with the use for which the bar is intended. It shows no fibre, breaks with a crystalline fracture, and shows fragments of slag and oxide of considerable size scattered through it.

For the production of No. 2 or "merchant bars," the lowest quality of bar iron used by the smith, puddled bar, is cut up at the shears into suitable lengths, and piled into oblong rectangular packets, which are then placed in a re-heating furnace, where they are raised to a welding heat, and in that state passed, with or without previous hammering, through the several grooves in a train of rolls which produce the desired section.

In the manufacture of No. 3, or "best iron," the pile or packet is made in the same manner as for No. 2, except that the top and bottom bars or plates of the pile are formed of No. 2 iron instead of No. 1, or the whole pile may be formed of No. 2 cut up and piled in the same manner as for the production of merchant from puddled bar. The pile is raised to a welding heat, and then again passed through the rolls. This quality corresponds to the best Staffordshire iron often mentioned in engineers' specifications, and is better adapted to the requirements of the smith than either No. 1 or No. 2, owing to its superior toughness and ductility over the low grades.

"Best-best" is a superior quality of bar iron, suitable for chains, anchors, rivets, etc., and is the result of the cutting up, piling, re-heating, and re-rolling of bars of No. 3 iron; while a further repetition of this process yields the "treble best" iron of the iron-master. The varieties of iron known by the names Best-best-best, etc., are not always made by the system of rollings described above, but often depend on the character of the iron used, Best-best iron being often produced from puddled bar by one piling, heating and rolling.

Malleable-iron is rolled into various "sections" at the mill—round bars, square bars, half rounds, L bars, Z bars, T bars, channels, and many other forms. As each form and each size of each form requires a separate pair of rolls, each mill usually rolls only a limited number of sections, and each firm issues a section book giving the sections it is

prepared to roll without the cost of making new rolls. Rails, girders, and heavy sections are now almost always rolled of mild steel.

“Nail rods” are the square bars used by nail-makers, etc., and are produced by cutting up the ordinary plates of the required thickness in a slitting mill, which consists of a pair of rolls fitted with collars, either turned on the rolls themselves or supplied by loose discs fitted to them. The rolls revolve together so that the collars in one roll fall into the spaces between the collars of the other, thus forming a series of circular cutters which act as shears upon the plate or bar passed between the rolls, and so cut up the metal into a number of small rods or bars.

“Iron plates” in like manner result from the rolling of suitably piled bars, the white-hot pile being first passed through the grooves of the blooming rolls for the production of a square bloom, which is then passed through the roughing rolls, and finally through the finishing rolls, the thickness of the bloom or plate being reduced at each successive passage between the rolls. The order of passage and mode of building up the pile for plates varies with the size of the plates. It is usual to describe all plates of a thickness below No. 4 Birmingham Wire Gauge (abbreviated B.W.G.)— $\cdot 238$ in.—as “sheets,” whilst all above such a thickness are called “plates.” “Black plates” are the thin sheets intended for tinning, and which, during the process of rolling, are doubled over upon themselves after every re-heating. This doubling is performed in the case of very thin sheets so that sixteen thicknesses are being passed between the rolls at once, before the plates are cut up to their proper and finished sizes. Sheets so produced are classified as “singles,” if between No. 4 and No. 20 B.W.G. ($\cdot 238$ in. to $\cdot 035$ in.) in thickness; or as “doubles” if between No. 20 and No. 25 B.W.G. ($\cdot 035$ in. and $\cdot 020$ in.) in thickness; and as “trebles” or “lat-tens” if between No. 25 and No. 27 B.W.G. ($\cdot 020$ inch and $\cdot 016$ inch) in thickness. It is necessary to add that in present day practice steel plates—not iron plates—are employed in the manufacture of tinplate and galvanised sheets.

CHAPTER XIV.

THE PRODUCTION OF MALLEABLE-IRON.

MALLEABLE-IRON may be produced direct from iron ores, or indirectly by first smelting the iron ore and then treating the pig-iron in the open hearth or reverberatory furnace.

The methods for the production of wrought-iron direct from the ores include the Catalan and similar processes, still used to a small extent in the Pyrenees, India, and some other places; the method of the American bloomery furnaces, and some more modern methods.

The methods for the production of malleable-iron by the indirect processes: (a) The treatment of pig-iron in the open hearth, as by the South Wales process; in the Lancashire hearth or Swedish finery, and similar processes; and (b) The treatment of pig-iron in the reverberatory or puddling furnace, this being the process by which the bulk of the malleable-iron is produced.

The direct processes necessitate the use of purer and richer ores and fuels than the indirect processes; since although ferric oxide is reduced at a red-heat by carbon-monoxide, yet the reduced iron is then left mixed with the gangue of the ore; but if the gangue be readily fusible, then the iron sponge produced by this reaction may be consolidated by hammering or squeezing into a comparatively solid bloom, and the scoriæ at the same time expelled. In the direct process readily fusible scoriæ permitting of being thus expelled can only be produced by using rich ores and extracting only a portion of the metal which they contain, the remainder of the iron escaping in combination with the silica and other impurities of the ore, and so producing readily fusible silicates rich in iron. Under these circumstances the carbon does not combine with the reduced iron in sufficient quantity to recarburise it to the condition of pig-iron.

The Catalan process is now little used, but it may be taken as a type of the primitive method for the direct production

of malleable-iron. The ores must be rich and readily fusible, and charcoal cheap and abundant; but even then the product is expensive, owing to the large consumption of fuel—from 3 to 4 tons of charcoal per ton of hammered blooms. Considerable manual labour is required and there is a heavy loss of iron in the slags, which are essentially rich ferrous silicates ($2\text{FeO}, \text{SiO}_2$), are not reducible by carbon-monoxide or by carbon at the temperature of the furnace. Owing to the fluidity and low temperature at which ferrous silicate slags fuse, the temperature attained in the furnace is always below that at which carbon combines readily with iron, and this, together with the decarburising influence of the

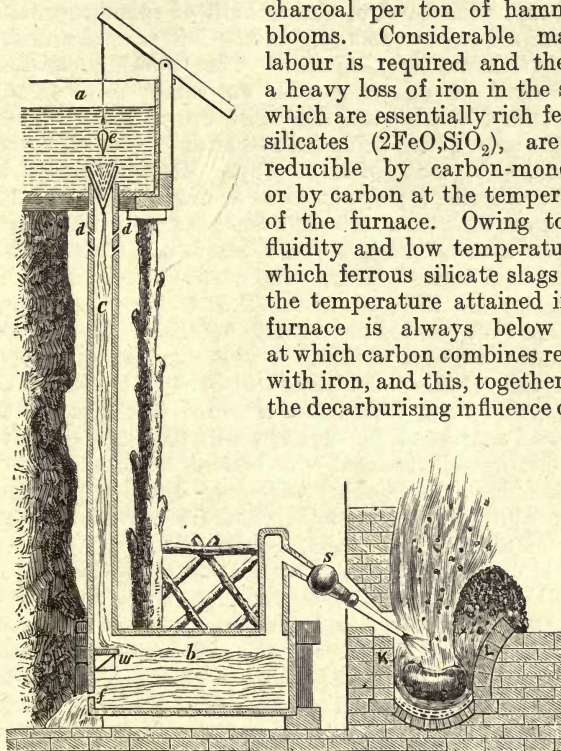


Fig. 66.—Catalan Furnace and Blowing Apparatus, Vertical Section.

slags, prevents the formation of cast-iron in the furnace. Therefore the product is iron; containing only a small proportion of carbon, but often enough to make it distinctly steely; which is not fused, but collects in masses at the bottom of the hearth.

The Catalan furnace (Fig. 66) consists of a quadrangular

hearth, about 3 ft. by 2 ft. 6 in., tapering to 2 ft. 2 in. at the bottom, the back of the hearth, through which the tuyere enters, being formed by the side of the building in which the furnaces stand. The furnace hearth is wider at the top than at the bottom, and is built of refractory masonry set in fire-clay, openings being left in the masonry for the escape of moisture. The working bottom of the hearth is of sandstone or some very refractory rock, and the sides *KL* are built up of heavy blocks of iron, the outer side *L* being built so as to form a convex curve. The conical tuyere is of sheet copper and into this the blast-nozzle is inserted; it is placed at an angle of 30° to 40° with the bottom of the hearth. The blast is supplied by a trompe or water-blowing machine, the blast being always highly charged with water vapour. The process of smelting is begun by clearing out the remains of the last charge and then distributing over the red-hot hearth burning charcoal; as this burns up the hearth is filled up with charcoal to the level of the tuyeres, after which a sheet-iron division is inserted across the hearth, and more charcoal is added to the compartment so formed nearest to the tuyere, whilst the other side farthest from the tuyere is charged with roasted ore, usually an easily reducible brown hæmatite containing from 40 per cent. to 45 per cent. of metallic iron. The ore is first broken into pieces of the size of an egg, and by raising the partition as required during the filling of the hearth the ore is heaped up on the side opposite the tuyere, and its surface finally covered over with damp charcoal and small ore; while at the same time the space between the ore and the tuyere side of the furnace is filled up with the larger pieces of charcoal. The blast is now put on slowly; as the temperature increases the reduction of the metal is effected, the charge at the same time sinking down, and fresh charcoal being added to supply the place of that consumed.

The slag and spongy iron produced collect in the hearth-bottom, the workmen all the time moving the descending pasty materials towards the blast-nozzle, whereby they are more strongly heated, and the slag better separated from the reduced metal. After about five hours sufficient metal will have collected in the bottom of the hearth to form a bloom, when the slag, which has throughout been tapped out at

intervals, is again run out, and the spongy mass of metal is withdrawn to be shingled under the steam-hammer to expel the slag and extraneous matters, and to consolidate the mass by welding together the spongy granular mass into a more solid bloom. Each charge of about $9\frac{1}{2}$ cwts. of ore, containing from 45 per cent. to 48 per cent. of iron, occupies altogether about six hours to work off, and consumes in its reduction about $10\frac{3}{4}$ cwts. of charcoal, yielding, after shingling, cutting up, re-heating, and again hammering, about 3 cwts. of iron bars. The reactions which take place are quite simple, the oxide of iron is reduced partly by carbon-monoxide and partly by the carbon to iron which separates, or to ferrous oxide which combines with the silica, forming ferrous silicate.

Bloomery furnaces, similar in principle to the Catalan forge, but having the sides made hollow so as to allow of the circulation of water to keep them cool, are still in use in remote parts of the United States and Canada, for the smelting of the rich and pure magnetic iron ores and titaniferous iron sands, the former for preference, since the latter are more refractory. The Bloomery furnace was formerly employed in England, but is now abandoned.

The High Bloomery or Stuckofen furnace, formerly employed on the Continent, occupied a position between the Catalan and Bloomery hearths just described, and the modern blast furnace; the Stückofen was a small furnace about 15 ft. high, and 3 ft. in diameter at the hearth, with only a single arch at the hearth, which was loosely bricked up when the furnace was at work, and used alike for the insertion of the tuyere and for the withdrawal of the bloom, or sometimes with a single tuyere opposite the arch. The blast was supplied by bellows driven by a water-wheel, and the slag was tapped out from a separate slag-hole at the proper intervals. The furnace was first filled with charcoal, which was ignited at the tuyere hole; then the tuyere was inserted and the blast turned on as soon as combustion was thoroughly active; the ore and charcoal were alternately added as required, and in about 24 hours sufficient metal had collected in the form of a bloom on the hearth to require removal, an operation effected by first removing the bellows and the tuyere, and then taking down the temporary masonry which closed the arch through which the bloom of spongy metal

was withdrawn for consolidation by shingling under the hammer. The bloom so obtained was cut up, refined in small hearths or bloomeries with bottoms lined with fine charcoal, and the refined bloom was again hammered out for the production of bars.

Many other methods have been suggested for the direct preparation of malleable-iron, either as a sponge or as welded masses. In the Hursgafel process oxide of iron was reduced by charcoal in an iron cased cupola with a movable hearth in which the bloom could be moved away to the hammers. In the Siemens direct process the ore was reduced by charcoal in a rotating furnace, and was balled up in the ordinary way. In the Chenot process an iron sponge was obtained by heating the ore and charcoal in an externally heated fire-brick retort, the charge being cooled by passing through a water cooled chamber before it left the furnace; and in Blair's process the reduction was brought about by producer gas. These processes were all abandoned when mild steel was introduced, and for so many purposes displaced malleable-iron.

CHAPTER XV.

PREPARATION OF MALLEABLE-IRON IN OPEN HEARTHS.

THE method of producing malleable-iron by the treatment of pig-iron in open-hearth fineries is of considerable antiquity but has now rapidly diminished in importance, and is almost extinct. The usual course is simply to melt pig-iron in shallow hearths, and then to expose it to the decarburising influence of a blast or current of atmospheric air directed upon its surface from an inclined tuyere. Another course is to use white iron approaching in composition to refined metal, and to introduce into the furnace such decarburising agents as hæmatite, hammer-scale, and the like, without any material assistance from the decarburising influence of the blast.

The operations for the conversion of grey pig-iron into malleable-iron upon the open hearth embrace three stages. In the first stage the grey iron is converted into white iron in a coke refinery; the second stage is that of lifting and breaking up the metal in the furnace, while the third or final stage is that of balling the product. The whole operation may be conducted in two separate furnaces consisting of one refinery, or running-out fire, working in conjunction with two charcoal fineries, or it may be completed in one hearth or fire. The former method represents the mode of procedure in South Wales, whilst the latter constitutes the German or Walloon process of Sweden, etc.

The South Wales process was employed to produce the metal for "coke plates." It consisted in the fusion of good quality pig-iron in a coke refinery or running-out fire, followed by a further fining and working of the refined metal so produced in a charcoal finery; the product was worked under the steam hammer or helve into large cakes or stamps of from $1\frac{1}{2}$ in. to 2 in. thick, and these are then re-heated in the hollow fire, forged under helves, and rolled into bars; these latter were then cut up into proper lengths for rolling out in the manner to be subsequently described, into sheets or plates of the required thickness.

The refinery or running-out fire was a small hearth, about 18 in. square, to which a blast of air was supplied through a pair of inclined tuyeres, which is employed for the conversion of grey into white iron preliminary to dry puddling in the reverberatory furnace. Worked in conjunction with the South Wales refinery were two charcoal fineries placed immediately in front of it but at a lower level, so that the charge of imperfectly refined metal could be tapped from the bottom of the refinery hearth, and run direct along inclined grooves or channels into the two fineries between which the charge of one refinery was divided.

The charcoal fineries were also small rectangular hearths surmounted by a chimney or stack and supplied with cold blast through a water tuyere. The hearth was formed of cast-iron plates, and the bottom was made hollow in order that it might be kept cool by the circulation of air beneath it; the side plates along three sides of the hearth were placed vertically, whilst the fourth or working side was made to slope outwards.

In the refinery or running-out fire coke was used as fuel, and upon the hearth, previously charged with coke, there was placed at each charge from 5 cwts. to 6 cwts. of pig-iron, which then slowly melted and collected on the bottom of the furnace, becoming partially decarburised and refined by the oxidising action of the inclined blast. The metal so collected in the hearth was then tapped out from the bottom and divided between two charcoal fineries, which were still at a red heat from the working off of the last charge. The charcoal fineries, after the withdrawal of a charge, were cleared of residual matter before the introduction of a fresh charge from the refinery, and any metal that remained on the hearth was collected into a ball to be added to the next charge. In tapping the metal from the refinery into the two fineries, the slag was kept back as much as possible, but a little always passed into the fineries and quickly solidified on the surface of the metal, from whence it was removed and a quantity of charcoal then thrown over the metal. At this stage the blast was turned on, and the partially solidified metal was broken up by the workman, who then drew the metal towards the tuyere side of the hearth whilst water was lightly thrown over the surface of the charcoal to prevent loss by its burning

away, and more fuel was added as required during the progress of the process. The residual ball of metal collected from the hearth after the withdrawal of the previous charge was now added, and in a little over one hour from the commencement, the workman having in the meantime constantly broken up and raised the metal from the hearth bottom towards the tuyeres, the metal would have "come to nature," as it is termed, and a lump of pasty, malleable metal, mixed, however, with much slag or cinder, collected in the bottom of the hearth, from whence it was withdrawn in one bloom or ball weighing something under 2 cwts. This bloom was forthwith shingled under the steam-hammer or under a helve of about 6 tons weight, for the production of a flat bar or slab $1\frac{1}{2}$ in. to 2 in. thick, which was nicked so that it could be broken up by the sledge hammer into pieces or stamps, weighing about 28 lbs. each. The fracture of each bar was examined, and only such slabs as presented a fairly crystalline and uniform grain of metal were used in the formation of the pile for the finished sheets. During the conduct of the process of fining, it was the practice to tap out the slag or cinder from the hearth two or three times, as might be required. Such slags or cinders were of a highly basic character, containing towards the end of the fining operation as much as 75 per cent. of oxide of iron.

The stamps obtained as above were subsequently piled upon the flattened end, from 12 in. to 18 in. long, of a staff made of a metal similar in quality to that of the stamps themselves. The pile formed by placing about three of the stamps upon the staff was raised to a welding heat in the hollow-fire, and then welded into a solid mass under the hammer, whereupon the slab so formed was nicked on the under side and then doubled upon itself, whereby the top and bottom surfaces of the pile are produced from the same surface of the slab. The pile was again raised to a welding heat in the hollow-fire and again welded under the hammer into a billet, which is taken whilst still hot, sheared from the handle of the staff, and at once rolled into a bar.

The particular method of procedure just described for the production of the hammered bloom was known as the method of "tops and bottoms," from their upper and lower surfaces being produced from the same face of the slab, and these

blooms were afterwards sent to the rolls for rolling out into sheets, of which the upper and lower sides present the same kind of surface.

The hollow-fire for reheating the stamps was a deep rectangular hearth or chamber of brickwork, arched over at the top, whilst in the sides are openings closed by sliding doors. The bottom of the hearth was formed of cast-iron plates, beneath which the air was free to circulate for keeping the plates cool. On the bottom plate was built a layer of fire-brick, and the hearth was not provided with any chimney or stack, but the gaseous products of combustion before escaping to the atmosphere, passed from the hollow-fire through a partition or wall between it and a second chamber in which the pile of stamps was placed for a preliminary heating before it was inserted into the flame of the hollow-fire. The firing door or stoke-hole was on one side of the chamber, and through this door the fuel (coke) was introduced on to the hearth bottom. The chamber was at all times only partially filled with fuel, and the combustion was maintained by a blast of air introduced from an inclined tuyere near to the surface of the fuel. In this manner the chamber or furnace above the fuel was filled with flame, which played around the stamps placed within it for reheating; the pile did not rest upon the bottom, but was supported in the midst of the flame, in which manner it is raised to a welding heat without coming into contact with the fuel, the handle of the staff all the time projecting beyond the furnace door.

The Lancashire hearth or Swedish finery is also a rectangular closed chamber or hearth, the sides and bottom of which are of cast-iron plates. The hearth communicates by horizontal flues with the stack, and the pig-iron is first placed in them for heating before it is drawn forward into the hearth itself. Through one tuyere is introduced a blast heated to a temperature of 212° F. (100° C.) by passing it through a series of iron tubes heated by the waste-gases of the finery; the blast is delivered at a pressure of from 1 lb. to $1\frac{1}{4}$ lbs. per square inch. The method of procedure with the Lancashire hearth is first to charge upon the heated hearth a quantity of charcoal; then to add from the flues or heating chambers a charge of about 2 cwts. of the pig-iron which has been heated there by exposure to the gases in the flues;

the blast is then turned on and more charcoal is added, in which manner the metal is slowly melted and trickles down before the blast, so that it is partially decarburised before it reaches the hearth bottom, where it partly solidifies or hardens. The workman is constantly engaged breaking up the metal with his bars and raising it before the blast for further fining and decarburisation. As the decarburisation thus proceeds, the metal becomes less fusible, and the workman is able to raise the whole charge to the top of the fuel in the hearth, and this being accomplished, it is immediately followed by the addition of fresh charcoal and an increase in the temperature by the turning on of more blast, whereby the partially fused metal is again perfectly melted, and thus better separated from the slag with which it is mixed; and this being effected, the fined metal is collected into a ball upon the hearth bottom, and is then withdrawn from the furnace, shingled as usual, and cut up into suitable lengths for piling and reheating, either in a separate fire or in a gas-furnace. The pile is then rewelded and further treated under the hammer or rolls for the production of malleable bars.

The fuel consumed in this hearth amounts to about 150 lbs. of charcoal per 100 lbs. of bars produced, whilst the process is attended with a loss of about 15 per cent. of the weight of the pig-iron introduced into the furnace or finery.

The Walloon process, like the Swedish-Lancashire hearth last described, is an example of the three operations of melting down, breaking up, and balling of the product in one and the same furnace, as a continuous operation, and is principally interesting as being the method according to which, in Sweden, the famed Dannemora malleable iron is produced. The furnace is a simple quadrangular hearth from 2 ft. to 2 ft. 6 in. wide, and about 10 in. deep; it is formed of thick cast-iron plates, and is fitted with an inclined tuyere through which the blast is introduced from two pairs of primitive bellows, worked by cams upon a revolving shaft driven usually by water power. The hearth is surmounted by a hood and chimney of brickwork, for taking away the gases, etc., from it. In one side of the hearth, and opening near the bottom of it, is an aperture through which the liquid slags produced by the process are tapped out.

The hearth, having worked off its last charge, is partially

cleaned by tapping out most of the remaining slag, but it is still necessary to leave in the hearth sufficient of the highly basic slag to assist in the decarburisation of the succeeding charge; for the fining in this process is always conducted in a bath of slag. Besides the slag, there will also remain a residue of incandescent charcoal, and upon this is placed the succeeding charge of from 2 cwts. to 3 cwts. of metal, previously cast into small pigs. The hearth is then filled up with fresh charcoal, and the blast is turned on, at first slowly, but more freely as the process goes on. The metal for refining soon begins to melt, and falls down in front of the blast in its descent towards the hearth bottom; it thus becomes partially decarburised and purified under the oxidising influence of the blast, the decarburising action being also assisted by the highly basic slags of ferrous silicate, which collect upon the surface of the metal in the hearth. The slags, as before mentioned, are tapped out through the slag-hole as their quantity becomes excessive, only sufficient being retained in the hearth to cover the fluid metal, and promote by its basic character the desired decarburisation of the pig-iron; but the richer portions of the slags tapped out are collected, and, along with the hammer-scale obtained in the hammering of the bars, are added to a subsequent charge during the first or melting-down stage of the process. A pasty mass of partially-refined iron thus collects in the bottom of the hearth, and the workman, with the assistance of a strong iron bar, then collects the metal into one mass or bloom, and raises it on to the top of the fuel, more fuel being at the same time added and the pressure of blast further increased. In this manner the metal again melts and passes down as before into the hearth, having undergone a further degree of fining or decarburisation, by exposure to the oxidising influence of the blast, so that the metal has by this time assumed a spongy condition. It is again collected into one bloom or ball, and withdrawn from the furnace to be shingled for the expulsion of mechanically-mixed slag and the consolidation and welding together of the spongy mass. The blooms weigh from 1 cwt. to 2 cwts. each, and are cut up at the same heat under the hammer into three or four pieces of suitable lengths, which are then reheated, and again hammered for drawing out into bars.

The melting-down stage of this process occupies from three to three and a half hours, and the whole operation, including balling and shingling of the blooms, requires about five hours. The hearth is worked much hotter than the ordinary charcoal finery, and the loss of metal is from 15 to 20 per cent. of the charge of pig-iron introduced, while the consumption of charcoal amounts to about 150 lbs. for every 100 lbs. of pig-iron treated. During the drawing down of the shingled bloom into bars some five or six reheatings of the metal are necessary, of which the first is effected in the finery hearth itself, during the first or melting-down stage of the process, the shingled bloom being held for this purpose by a pair of suitable tongs in the fore part of the hearth, where the temperature is sufficient to heat the bloom almost to a welding heat ; but the later reheatings are effected in a separate fire.

The exact method of procedure observed in the working of the Walloon process varies somewhat from that described above in different works and localities. Thus, instead of introducing the charge on to the hearth in the form of small pigs or slabs, it is not unusual to prepare white or mottled pig-iron in slabs of 15 ft. or 16 ft. long and 3 in. thick, and when the hearth is filled up with charcoal and the blast turned on, a slab is introduced by resting it on a roller in front of the hearth, whilst its extremity is pushed over the plate in front of the tuyere, and so held in the middle of the hearth at a distance of 9 in. or 10 in. above the bottom. The end of the slab is thus presented to the high temperature of the hearth near the tuyere, and as it melts down it is gradually pushed farther into the hearth until in this manner the amount of metal required to produce a bloom of about 100 lbs. in weight has been introduced. By this method the fining or "coming to nature," is very rapid ; and the workman during the melting down also constantly rabbles the metal with iron bars as it collects on the hearth.

The metal produced in these charcoal or Walloon fineries is of a superior quality ; but it is deteriorated when hot-blast and coke instead of cold-blast and charcoal are employed.

CHAPTER XVI.

PUDDLING.

ALMOST all the malleable-iron of commerce is now prepared by puddling, a process which was invented by Cort in 1784. It consists in heating the pig iron on the hearth of a small reverberatory furnace with free access of air till the carbon and silicon are oxidised out. Cort used a furnace with a sand bottom, and used white iron, which never became liquid, but remained during the whole process in a more or less pasty condition, and this form therefore was called dry puddling. In the modern form of the process grey iron is used. This melts perfectly, and the escape of carbon monoxide produces the appearance of boiling. The process is therefore called wet puddling or pig boiling.

The puddling furnace employed in Staffordshire (Figs. 67 to 71) has a hearth of the form shown in Fig. 69, with a low flat arch or roof of fire-brick, *z* (Fig. 71), sloping gradually from over the front wall of the fireplace to the flue at the stack end of the furnace. In the small single furnaces the roof is higher at the working side over the door than it is at the opposite side. The fire-bridge, *a*, between the hearth, *c*, and the grate, *b*, is formed of a hollow cast-iron frame encased in fire-brick, while the flue-bridge, *n*, across the other end of the hearth, separates the hearth from the flue and the stack. The last-named, *y*, is built of common red bricks lined with fire-brick; for one furnace only it ranges from 30 ft. to 50 ft. high, and is strengthened, as shown, by angle-irons up each corner, and well braced together by tie-rods passing around the stack. The stack is surmounted by a damper connected with a lever and chain, the latter brought down within reach of the puddler that he may regulate the draught as required during the working of the process. The outer, or the side and end walls of the furnace, are enclosed within strong cast-iron plates *d*, *d*

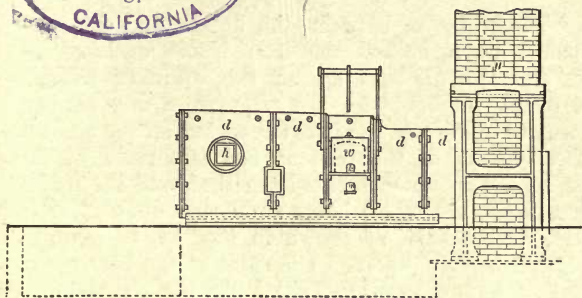


Fig. 67.—Puddling Furnace, Front Elevation.

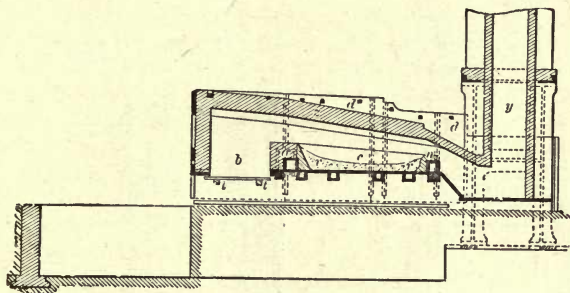


Fig. 68.—Puddling Furnace, Vertical Longitudinal Section.

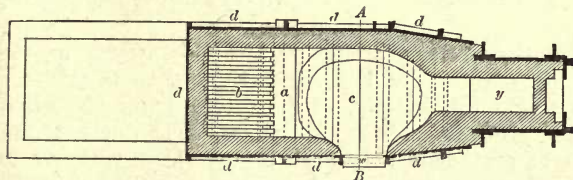


Fig. 69.—Bed of Puddling Furnace, Horizontal Section showing Plan.

(buckstaves), bolted together through suitable flanges, and the plating of one side is connected with that on the opposite side by tie-bolts, or rods, passing from side to side over the top of the furnace.

The hearth *c* is about 6 ft. long and about 3 ft. 9 in. wide at the fire-bridge end, and 2 ft. 9 in. at the flue-bridge

end. The bridge *a*, between the hearth and the grate-bars is formed of a hollow cast-iron frame enclosed in fire-brick, and the fire-bars are of the ordinary wrought-iron type, readily movable for the removal of any clinker, etc., adhering to them, and they are supported on the usual bearers *t*. The bottom of the furnace bed is formed of cast-iron plates, which are often rebated together, and the joints carefully caulked, the whole being supported upon dwarf pillars, bearers, or brackets, as shown in Fig. 68, to permit of air circulation beneath them. The sides of the hearth are often formed of hollow castings cooled by the circulation of air through them; they are covered at the top and back by

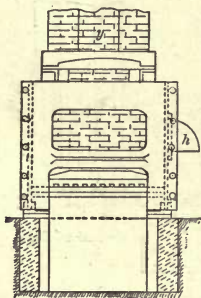


Fig. 70.—Puddling Furnace, End Elevation.

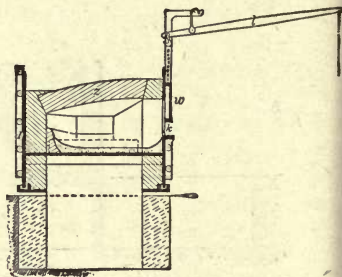


Fig. 71.—Puddling Furnace, Transverse Section on Line A B (Fig. 69).

brickwork, which overlaps or projects inwards at the top or upper edge beyond the side castings, so as to form a recess into which the fettling, or refractory lining, is introduced for the protection of the side plates. The depth of the fireplace or grate-bars below the bridge varies with the nature of the fuel to be consumed, a greater depth being required for slightly bituminous coals. But the best fuel for the ordinary grate is a non-caking coal rich in hydrogen, this burning with the production of a long flame which plays over the whole length of the furnace hearth. The area of the grate-bars is from one-third to one-half of the area of the bed, being thus considerably larger in proportion to the area of the bed than is required with the reheating, balling, or ordinary reverberatory furnace. The

firing-hole, *h* (Figs. 67 and 70), is in the front or working side, with its sill-plate about 10 in. above the level of the grate-bars ; it is not, however, closed by any door, but after firing or the introduction of the necessary fuel on to the grate, it is stopped by placing upon the sill of the fire-hole a few lumps of coal, and then throwing over these a shovelful of small coal against the opening into the grate. The working door *w* is placed some 10 in. above the bed of the furnace, and it is closed by a door formed of a large fire-brick tile, slab, or quarry fixed in an iron frame, and suspended by a chain from a lever, *l* (Fig. 71), at whose opposite end is a counterbalance weight and suspended chain, by means of which the door can be readily raised and lowered for introducing the charge and withdrawing the puddled balls ; for these purposes only is the door used, the working of the charge being effected without opening the door by the puddler introducing his bars or paddles through the stopper-hole *k* (Fig. 71), the sides or edges of which serve as a fulcrum for the rabbles during the stirring and working of the charge. In Scotland the furnaces are always worked with a closed ashpit, a jet of air and steam being blown in at the chimney end passing under the hearth and thence to the fireplace.

Large or double furnaces have two working doors, one on each side ; they require two sets of men for their manipulation and are equivalent to two ordinary furnaces, but more economical in fuel.

Below the sill-plate of the working door is the tap-hole (Fig. 67), which is stopped with sand during the working of the furnace, and through which the slag or cinder is withdrawn ; the cinder also flows over the flue-bridge during the working of the furnace, and collects at the bottom of the stack. For burning bituminous coal the area of the flue requires to be about one-fifth of the superficial area of the grate-bars, but for anthracite coal the sectional area of the flue is but one-seventh of the grate area. In Scotland no slag is tapped out, but it is allowed to boil over the sill of the door into a " bogie " put to receive it.

Preparing the Hearth.—The working bed (Fig. 68), or lining of the hearth of the puddling furnace, was formerly of sand, but is now always made of refractory substances rich in the oxides of iron, such as hæmatite hammer-scale mixed, or

similar material, such matters aiding by their oxidising character in the conversion of pig-iron into malleable- or wrought-iron. The bottom is prepared by first putting on the hearth a layer of broken slags, tap-cinder or hammer-scale, and then raising the temperature sufficiently to soften these materials that they may be spread over the bottom to a uniform depth of about 3 in.; upon this is placed a layer about $1\frac{1}{2}$ in. thick of a "fettling" consisting of a nearly pure oxide of iron, in the form of a soft red hæmatite known by the name of "puddler's mine," iron scale or purple ore, or similar material. The side plates are also fettled or covered with a lining consisting of oxide of iron or of roasted tap-cinder, or "bull-dog," as it is technically called, which is rammed well in under the projecting rib of brickwork or fire-clay slabs covering the top edge of the side plates. Much importance is attached to the fettling being fixed as close and dense as possible around the furnace for the production of a cleaner iron.

ANALYSES OF THE MATERIALS EMPLOYED AS FETTLING FOR THE
PUDDLING FURNACE.

	Bull-dog.	Purple ore.	Pottery-mine.
Ferrous oxide	3·55	—	46·53
Ferric oxide	63·90	95·10	—
Manganous oxide	—	—	2·54
Silicon	15·75	—	—
Titanic acid	10·89	—	—
Phosphoric anhydride	·93	—	0·69
Carbonic anhydride	—	—	30·77
Sulphur	0·35	0·07	—
Sulphuric acid	—	—	0·04
Iron pyrites	—	—	0·34
Copper	—	0·18	—
Lead (as sulphate)	—	1·29	—
Lime	—	—	2·41
Calcium	—	0·49	—
Alumina	—	—	0·97
Sodium	—	0·29	—
Magnesia	—	—	1·39
Insoluble residue	—	2·13	2·27
Water and organic matter	—	—	11·93
	—	99·55	99·88

A good fettling should melt with a clear face. Should it tend to crumble away, and so to become mechanically mixed in an unfused condition with the metal of the puddled ball, it will be exceedingly difficult, if not impossible, to expel it during the hammering or rolling of the bloom into finished iron, and its presence will produce laminations of slag in the finished bar. Lime is sometimes used for fettling, but anything of a quartzose or siliceous nature is to be avoided, and good materials for the purpose are best tap-cinder obtained from reheating furnaces working with cinder bottoms employed in heating the wrought-iron piles for the rolling mills, hæmatite ore free from silica, iron scale, purple ore, or similar materials.

The puddling furnace, when maintained in regular use, requires rebuilding after about six months' work.

Working a Charge.—The actual manipulation of the charge in the puddling furnace may be divided into four stages. During the first or melting-down stage, occupying about 35 minutes, the iron melts and a large proportion of the silicon is oxidised. In the second stage, a comparatively low temperature is maintained, by lowering the chimney damper; the charge requires to be thoroughly mixed with the slag formed during melting down or any oxidising materials added to the furnace, so the puddler during this stage draws down the metal from around the sides, and mixes it with the more fluid metal and cinder in the middle of the hearth. During the third stage the damper is raised, the temperature is increased considerably, and violent reaction ensues, marked by the copious evolution of carbon-monoxide, which, escaping through the slag on the surface of the metal, gives rise to the appearance of boiling. In this stage oxidation is promoted by the constant stirring or rabbling which exposes fresh surfaces of the metal to the oxidising influences; at the same time there is produced a fusible slag or cinder consisting of silicates of iron, but containing also excess of ferric oxide, phosphoric anhydride, earthy matters, etc. Near the end of this stage the ebullition gradually subsides, and the surface of the charge "drops," as it is called, and the whole mass lies in a pasty state on the furnace bed, where it is worked as thoroughly as possible by the puddler, so as to allow the flame to play uniformly over all parts

of the charge. The fourth and last, or balling stage, consists in breaking up the contents of the furnace into some half-dozen balls, which are each rolled towards the fire-bridge of the furnace to receive a final welding heat before being withdrawn to the steam hammer, helve, or squeezer for the expulsion of slag and the production of puddled bar. During the four stages mentioned the damper is raised and lowered several times to regulate the heat, and to adjust the amount of air passing through the furnace.

Supposing the furnace hearth to be hot from the working off of a previous charge, and to contain some of the rich cinder produced during the last heat, the puddling or pig-boiling process is begun by first fettling the sides of the furnace, and then introducing about $4\frac{1}{2}$ cwts. of pig-iron. The working door is lowered, and if necessary made air-tight by luting. The damper is raised, the fire-hole opened, and more coal added to the grate. The fire being thus made up, the fire-hole is again stopped by lumps of coal covered over with coal slack as before, and after an interval of about fifteen minutes the metal begins to soften, and the puddler then inserts his rabble or bar through the stopper hole in the lower edge of the working door, turning over the pigs of metal so as to heat them and the hearth bottom more uniformly; and as the metal melts he also draws down any portions of unmelted metal from the sides towards the middle of the hearth. In from thirty to thirty-five minutes from the start, the melting-down stage is complete; then the damper is lowered, and the melted or pasty metal is briskly stirred to incorporate it thoroughly with the oxidising cinder, while hammer-scale or mill-cinder may be added to increase the basicity of the slags, and to combine with the silica produced by the oxidation of the silicon as well as with that introduced in the form of sand, which always adheres more or less to the pig-iron as received from the blast furnace. When the charge has thus become covered with slag or cinder, the damper is again raised and the temperature thereby increased, so that in about forty-five minutes from the start the metal swells and rises rapidly, at the same time appearing to boil, due to the escape of carbon-monoxide resulting from the oxidation of the carbon in the pig-iron by its reaction with the oxides and silicates of iron contained in the basic slag covering the metal

in the furnace. These decompositions are promoted during this stage by the vigorous rabbling of the charge by the puddler. He constantly moves the metal from the centre of the hearth towards the bridges, whilst at the same time cleaning well around the sides of the furnace.

During the boiling period the escaping carbon-monoxide (CO) burns at the surface of the bath with its characteristic blue flame, and the slag swells up and boils over the sill of the door, and as the decarburisation thus proceeds the mass begins to stiffen, the boiling decreases, the cinder gradually falls or "drops," and the metal "comes to nature," a condition indicated by the appearance of malleable-iron in the form of bright points or specks on the surface of the charge, the points as the process proceeds increasing in size and collecting into pasty masses, when the contents of the furnace are again broken up and mixed by persistent rabbling, and any pasty lumps observed to be sticking to the furnace sides are detached and drawn down towards the centre of the bed, when the heat is again raised somewhat, so as to thoroughly liquefy the slags or cinder, and so promote their separation from the metal.

The last, or balling stage, then ensues, during which the workman detaches a portion of the pasty metal and rolls it over the surface of the furnace bed until it forms a ball weighing from 60 lbs. to 80 lbs., having sufficient cohesion to bear removal from the furnace. Each ball is rolled towards the fire-bridge, where it lies as little exposed as possible to the oxidising current of atmospheric air passing between the working door and the chimney. After the whole charge has been thus collected into about six balls, a final heat is given, after which the balls are withdrawn with tongs, and dragged on to a two-wheeled bogie or truck, which then is wheeled to the hammer, squeezer, or other shingling apparatus. The metal is here welded together into a comparatively solid mass, much slag and cinder being expelled. During the withdrawal of the balls the damper is lowered somewhat, so that a smoky, non-oxidising flame is maintained within the furnace, and the metal suffers but little, therefore, from oxidation and waste during this operation; but if the puddled balls remain

too long in the furnace the quality of the metal is greatly impaired.

The pigs of iron are charged and piled near the fire-bridge of the furnace, and as the temperature rises they are drawn down by the workman to the centre of the hearth, and there forced beneath the surface of the fluid slag; the iron sinks down, forming a fluid bath beneath the molten cinder, which protects it from the direct action of the air, unless to bring fresh portions under the oxidising influence, and the oxidation is therefore brought about indirectly by the action of the oxygen in the slag which is continually rabbled into the molten metal.

Upon a new furnace bottom the first charge is made up chiefly of scrap-iron or waste-blooms and refined metal, so that by working this at a high temperature the bottom becomes consolidated and coated with a layer of slag consisting largely of iron oxide, which is but little acted upon by the silicon of the pig-iron subsequently introduced. If grey pig-iron containing much silicon be introduced on to a new bottom as a first charge, the silica resulting from its oxidation acts rapidly upon and unduly destroys the bottom.

The puddler's tools consist only of a long, straight chiselled-edged bar called a "paddle," and a hooked flat-ended bar known as the "rabble," and as these become very hot, each one as it is taken from the furnace is cooled by being plunged into water, and a second one is taken into use.

Pig-iron for Puddling.—Whilst almost any variety of iron could be puddled, that selected, where there is free choice, is a grey iron, almost No. 4, preferably showing a rose—that is, a small portion more coarsely crystallised—in the centre of the fracture. Such an iron will contain about 1 to 1.5 per cent. of silicon.

High silicon is objectionable for several reasons:—(1) It entails considerable waste, as the silica formed will combine with oxide of iron to form silicate. (2) It unduly prolongs the process. (3) The slag formed when the iron is melted down is siliceous, and therefore remains pasty at the temperature of the furnace. It may even remain pasty to the end, when it will not be easily removed by shingling, and the quality of the iron will be injured. When the slag is not sufficiently fusible, the workman says the charge is "cold."

This may be remedied to some extent by the addition of oxides of iron.

If the silicon is too low, the slag will contain an excess of difficultly fusible oxide of iron, or will be dry, and the iron will probably be white, and so unsuitable for "wet" puddling. Phosphorus is an objectionable constituent. About 80 per cent. of the phosphorus present is removed, and the pig-iron should not contain more than .9, or at most 1 per cent. of phosphorus.

Slags Produced.—Tap-cinder is the slag produced during the puddling process. It is tapped out into wrought-iron waggons after the withdrawal of the last ball of every second heat, or it runs over the sill into the bogies, in which case it is usually called puddlers' cinder. In Scotland the slag is not tapped out except when the furnace is required empty for repairs. During the boil a large quantity boils over the sill, and the remainder is left in the furnace. When scrap-iron is "balled" the slag is nearly pure black oxide of iron. The scrap is, of course, not melted, but is welded together at a high temperature.

In "puddling" the oxidation is effected not directly by the air but mainly by oxide of iron contained in the slag and to some extent by the oxidised materials used in the fettling of the furnace. During the earlier or melting-down stage, in which the silicon of the pig-iron is being oxidised, and the cinder produced is siliceous and contains very little free oxide of iron, there is very little removal of carbon; but as the process proceeds, and the proportion of silicon in the pig-iron becomes largely decreased, and enough iron has passed into the slag to make it basic, the reaction between the cinder or slag and the combined carbon of the metal increases in activity, and there is the copious evolution of carbon-monoxide and a corresponding decarburisation of the metal, and at the same time a reduction of iron from the slag or cinder.

Sulphur is but imperfectly eliminated from the charge in puddling; some of it passes into the slag (tap-cinder), where it probably occurs as a sulphide of iron; but the elimination of sulphur, as far as it goes, appears to proceed somewhat steadily from the beginning to the end of the puddling process. The conditions favourable to the elimination of sulphur from the malleable-iron are: (a) regularity of working; (b) the presence

of a good basic slag or cinder, produced by the addition of a fettling rich in oxide of iron, oxide of manganese, lime, etc.; (c) sufficiently lengthy contact of the iron with the cinder before the beginning of the boil, and hence any delay in the process tends to the removal of a larger proportion of sulphur, as also of phosphorus.

The elimination of phosphorus is likewise imperfect. About 80 per cent. of the phosphorus in the pig-iron passes out during puddling, and the tap-cinder produced at the same time always contains a considerable amount of phosphoric anhydride ($P_2 O_5$) (see analyses, p. 203).

Manganese, when present in considerable proportion, delays the fining of the pig-iron as it oxidises to a large extent before the iron; it also promotes the better elimination of sulphur from the puddled product. The manganese is to a large extent oxidised early in the process.

Time, etc., of Working.—A “heat” is the time occupied between charging the pig-iron and drawing the last ball of malleable-iron from the furnace, and is generally about $1\frac{1}{2}$ to $2\frac{1}{2}$ hours, the time being longer or shorter according to the purity of the original pig-iron.

The loss in the puddling process varies according to the purity of the pig-iron, for since foreign ingredients are more or less completely removed during the process, it follows that the greater the impurity of the iron the greater will be the loss, but much depends on the skill of the workman. The loss in Staffordshire is from 7 to 10 per cent. and in Scotland somewhat more. The loss is less than that calculated from the impurities removed, as some iron is always reduced from the fettling of the furnace or from oxides added.

Fuel consumption per ton of puddled bars produced is about 1 ton both in Staffordshire and Belgium; about 25 cwts. or 26 cwts. in Scotland; from 24 cwts. to 27 cwts. in the Cleveland district; and about 30 cwts. at Bowling, Farnley, and Low Moor in Yorkshire.

The fettling used during one shift (the charge is 4 cwts. to $4\frac{1}{2}$ cwts.) is from 6 cwts. to 7 cwts. of “bull-dog” and 2 cwts. to 3 cwts. of “blue billy,” in Staffordshire.

The tap-cinder, or slag produced during the puddling process, is a highly basic silicate varying in composition at

various stages of the process, but always containing ferrous and ferric oxide, with manganous oxide, alumina, lime, magnesia, ferrous sulphide, phosphoric anhydride, and probably some phosphide of iron. It often yields from 45 to 55 per cent. of metallic iron, existing principally in the form of ferrous and ferric oxides. The basicity of the cinder is greatest towards the end of the process as the metal "comes to nature," since then the oxidation of silicon has been practically completed, whilst owing to the high temperature still prevailing within the furnace the oxidation or waste of iron continues. The cinder expelled during the shingling of the puddled ball is almost invariably richer in silicon and phosphorus, but poorer in iron, than that left on the bed when the balls are withdrawn from the furnace. During the melting-down stage of the puddling process, the cinder is the most siliceous, as is shown by the accompanying analyses, for during this stage the silicon of the pig-iron is being rapidly oxidised by the oxygen of the atmospheric air; also the silica in the form of sand attached mechanically to the pigs of cast-iron likewise passes at this stage into the slags, in combination with oxide of iron, etc.

The following are analyses of tap-cinder taken at various periods of the puddling process in an Upper Silesian works, working upon a charge weighing $4\frac{1}{2}$ cwts. of a mixture made in the proportion of 24 cwts. of hæmatite pig to 20 cwts. of white iron:—

ANALYSES OF TAP-CINDER.

	A	B	C	D
Silica	17·13	21·91	19·45	16·29
Ferrous oxide	59·06	46·76	48·04	51·62
Ferric oxide	9·81	12·36	13·48	19·32
Manganous oxide	9·35	15·87	14·40	8·46
Alumina	0·35	0·30	0·34	0·38
Lime	0·69	0·43	0·62	0·61
Phosphoric anhydride	3·40	3·10	4·17	3·78
Iron	52·80	45·02	46·79	53·67

A.—After complete fusion of charge. B.—Before end of refining. C.—At "coming to nature" of first ball. D.—Slag from hammer during shingling of first ball.

ANALYSES OF STAFFORDSHIRE TAP-CINDER.

	A	B	C
Silica	7.71	23.86	11.08
Ferrous oxide	66.32	39.83	63.00
Ferric oxide	8.27	23.75	17.14
Manganous oxide	1.29	6.17	—
Alumina	1.63	0.91	—
Lime	3.91	0.28	—
Magnesia	0.34	0.24	—
Ferrous sulphide	—	0.62	—
Sulphur	1.78	—	0.48
Phosphoric anhydride	8.07	6.42	8.20
Titanic acid	—	—	—
Metallic iron	57.37	47.60	—

A.—Cinder from boiling of white iron (Riley). B.—Staffordshire cinder (Percy). C.—Cinder from pig-boiling.

Modifications of the Process.—Double puddling furnaces manipulated by two sets of men have two working doors, one on each side, through which the metal is simultaneously worked by the puddlers. The metal produced by them is not likely to be of such good quality as that produced in the smaller single furnaces, owing to the difference in skill between the workmen on the two sides, the furnace working hotter on one side than the other, the longer time that the charge is within the furnace, and the increased volume of air passing through. But owing to larger charges, amounting to from 10 cwts. to 15 cwts. per heat, as against the 4 cwts. or $4\frac{1}{2}$ cwts. worked in the single furnaces, they have a larger output and a greater economy in fuel and fettling.

It is the practice in some works to add small quantities of Cumberland red hæmatite (consisting largely of ferric oxide) to promote the reactions of the boiling process. Scrap-iron added towards the end of the boiling process is also considered, under favourable circumstances, to improve the product. Gas furnaces have been tried for puddling, but have never come into extensive use. The higher temperature obtainable by the gas furnace is no advantage—rather the reverse—in puddling. When used as a rule the producer is attached to the furnace, and no regenerators are used.

What is known as Parry's process of double or treble puddling consists in taking iron which has been once puddled

according to the ordinary practice, such as ordinary scrap iron, etc., and reconverting it into a kind of pig-iron, by melting in a cupola with coke, and this is then again subjected to the puddling operations. This process is not now used, its only advantage being that it allowed the use of irons higher in phosphorus than could be used for the production of malleable-iron by one puddling.

Various mechanical rabbles have been proposed to aid or supersede the very exhausting manual labour required from the puddler; but these appliances are not applicable to the balling-up of the charge, which has still to be done by the fore-hand at the furnace, and the weight of the charge is accordingly still limited by the power of the workman to ball it up. Mechanical rabbles have not, therefore, come into general use, although they enable the puddler to work somewhat larger heats, and occasionally to effect a slight economy in the working.

Revolving furnaces were also introduced to relieve the puddler of a part of his very arduous labour. In these the hearth consists of a revolving cylinder rotated by steam power. They were expected to produce malleable-iron more economically and of greater homogeneity than by the older fixed furnaces, but these expectations have not been fully realised. The introduction of revolving furnaces appears to date from the Messrs. Walker and Warren's furnace of 1853. Among the more or less successful forms of revolving hearth of more recent date are those of Danks, introduced in 1869, of Sellers and Siemens, each in 1871, and of Crampton, in 1872 and 1873. In these furnaces the hearth revolves in a vertical plane, whilst in others, as in those of Pernot, Godfrey and Howson, etc., it rotates in a plane either horizontal or only slightly inclined to the horizontal.

Waste Heat.—The puddling furnace is very wasteful of heat as owing to the short hearth the products of combustion leave the furnace at a very high temperature. In modern works these gases are passed through the flues of steam boilers, and thus enough steam is raised to supply the needs of the works. The boilers are of the usual Lancashire type, and may be placed either at the end of or above the furnace. The latter is the more usual position, and one boiler is heated by the waste heat from two adjacent furnaces

CHAPTER XVII.

REFINING PIG-IRON AND DRY PUDDLING.

PIG-IRON that is to be made into malleable-iron by the process of dry puddling, as distinguished from wet puddling or "pig boiling," has first to be refined into a partly decarburised and desilicised white or refined iron. In all puddling processes, pig-iron is converted to malleable iron by oxidation; but in dry puddling this oxidation is almost entirely dependent upon the action of the atmospheric oxygen, whereas in the "wet" process, the slags are rich in iron oxides which exert an oxidising action. Dry puddling is applicable only to the working of white iron because this in passing from the solid to the liquid state assumes a soft pasty condition highly favourable to oxidation by the oxygen of the air. White iron from the blast furnace is rarely used, because it is liable to contain a considerable quantity of sulphur.

The refining of pig-iron now under consideration is, therefore, only preliminary to the puddling of the metal in the reverberatory furnace. It consists in melting pig-iron, and directing upon its surface a blast of atmospheric air from several inclined tuyeres, whereby the silicon in the pig-iron is largely oxidised. The silica unites with ferrous oxide to yield a highly basic slag of ferrous silicate containing also some of the phosphorus and sulphur present in the original pig-iron. The iron is now a white or partially purified refined metal, capable of being more readily and quickly converted into malleable-iron in the puddling furnace, owing to its decreased fluidity, and its greater purity. The refined metal may be run directly from the refinery to the puddling furnace, but it is more usual to cast it into forms easily broken up into pieces suitable for introduction into the furnace. It must be understood that whilst the object of the Swedish and German fineries already described was the production of malleable-iron direct, the product of the English refinery now being considered is only the production of a white iron

which must be treated in the puddling furnace before it becomes malleable-iron.

The Finery.—The English refinery or running-out fire (Figs. 72 and 73) consists of a strong cast-iron frame-

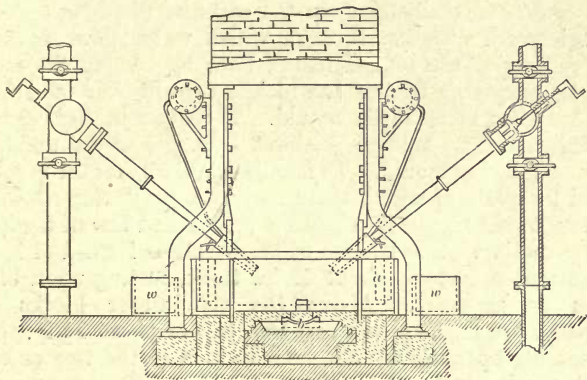


Fig. 72.—Refinery for Converting Grey into White Iron, Elevation.

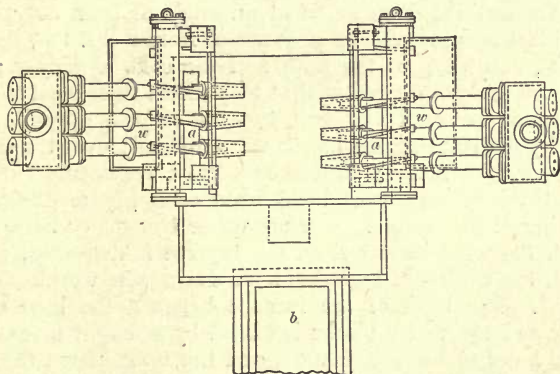


Fig. 73.—Plan of the Refinery and of the Mould for the Refined Metal.

work, surmounted by a low brick chimney or stack from 16 ft. to 18 ft. high. The hearth is about 4 ft. square and from 15 in. to 18 in. deep, bounded on two sides and at the back by cast-iron water blocks,

a, a, through which blocks water circulates. The front side of the hearth is closed by a cast-iron dam-plate, containing the tap-hole from which the metal and slag flow into the casting-pit or pig-mould *b*, about 12 in. wide and 14 ft. to 16 ft. long. This pig-mould is in front of the refinery, and rests longitudinally upon the edges of two long cast-iron or brickwork cisterns, through which water flows to assist the cooling of the refined metal, both by cooling the mould and by supplying the water which is thrown over the surface of the heated metal in the mould. The water in these cisterns is maintained at a level of about 1 in. below the underside of the pig-bed or mould. To facilitate still further the breaking up of the plate of metal, there may be a projecting rib in the bottom of the mould to produce a groove and line of weakness in the casting. The bottom of the hearth is formed of blocks of dressed sandstone about 12 in. thick, resting upon brickwork or masonry. Above the side water blocks and carried upon lugs, are the cast-iron tuyere plates $2\frac{1}{2}$ in. thick, containing openings for the introduction of the two or three blast nozzles or tuyeres upon each side of the hearth. The water tuyeres are usually from $1\frac{1}{2}$ in. to $1\frac{3}{4}$ in. in diameter, and are inclined downwards at an angle of from 30° to 35° . The blast is supplied at a pressure of from 2 lbs. to 3 lbs. per sq. in., according to the nature of the coke employed; and the tuyeres are arranged so that they direct their blast towards the space between the two tuyeres on the opposite side, thereby distributing the blast more uniformly over the surface of the molten metal; each nozzle has a regulating valve for adjusting the supply of blast from each tuyere during the working of the charge. *ww* are water troughs or boshes into which the waste water from the tuyeres is delivered, and in which the workman cools his tools during the working of the charge. The back of the furnace between the base of the stack and the water blocks is closed by wrought or cast-iron doors hung to the side frames, and the front above the dam-plate is also closed by a sliding door, connected with a lever by which it can be readily raised or lowered. A dust-plate is also usually fixed on the dam-plate to facilitate the filling and working of the fire.

In the Yorkshire refineries two tuyeres only are employed, both on the same side of the hearth. The hearth is 4 ft. by

3 ft. 4 in., and is 1 ft. 6 in. deep ; it is surrounded by water cooled blocks, and the refined metal is cast in sand moulds into cakes about 3 in. thick. In some of the smaller refineries only one blast nozzle is used, it being introduced at the back of the furnace.

When the charge is made up of selected pig-iron, old castings and other scrap, etc., the refinery is distinguished by the term "melting-down" ; and when the molten pig-iron is run direct from the blast furnace into the refinery as "running-in."

The refinery works continuously—that is the hot hearth after tapping out a charge is immediately prepared for the next. When starting a new hearth or after a stoppage, some broken sandstone is spread over the floor and a fire made in the centre ; coke is added through the folding doors at the back of the furnace, and a light blast is turned on ; then the charge of pig-iron, scrap, and coke is introduced by piling on the materials in alternate layers, until the whole charge, averaging about 2 tons of metal in the larger furnaces, has been made up, when more fuel is added to the top of the pile, and the full blast turned on. Such a charge requires about 6 cwt. of coke for its refining, and the process occupies from three to four hours, grey iron taking slightly longer than white iron. The refining is accelerated by adding basic slags, cinders, hammer-scale, etc., which act as oxidising agents and slightly increase the total yield of iron, since the carbon of the pig-iron is partially oxidised by the oxygen of the oxides of iron present in the scale or cinder, and an equivalent amount of iron is at the same time reduced and added to the yield.

The first effect of the heat in the newly-erected or repaired refinery is to soften the sandstone and glaze the surface of the hearth. The pig-iron of the charge begins to melt after about one hour, and the iron trickles down through the mass of coke on to the bottom of the furnace, where, in from 90 to 120 minutes, the whole of the charge collects, and so lies fused beneath the coke. More coke is now added, and the blast is continued for another half-hour or a little more, during which time more silicon from the pig-iron is oxidised, producing silica, which, together with an additional amount of silica derived from the ash, etc., of the fuel, combines with the ferrous oxide (part of the iron oxidised by the blast) to produce a highly basic and readily fusible slag or cinder

approaching to monosilicate of the formula of a $2\text{FeO SiO}_2 = \text{Fe}_2\text{SiO}_4$, containing from 40 to 60 per cent. of iron, and presents when cold the very dark-blue or black colour and the vitreous, lustrous fracture of usual cinders rich in iron. Such a slag has a powerful oxidising influence upon the molten metal beneath it, and thus under the joint influence of slag and blast, the silicon with smaller quantities of carbon, sulphur, and phosphorus and the greater portion of the manganese present in the original pig-iron are oxidised, as indicated by analyses below of the original pig-iron, and of the refined metal obtained therefrom. More fuel is added until the desired degree of fining has been effected.

ANALYSES OF REFINERY CINDER OR SLAG.

				Dowlais (Riley).		Bromford Crystallised cinder. (Forbes).
				Ordinary cinder.	Crystallised cinder.	
Ferrous oxide	..	..	..	65.52	54.94	61.28
Silica ..	..	..	..	25.77	33.33	22.76
Manganous oxide	..	..	..	1.57	2.71	3.58
Alumina ..	..	..	..	3.60	5.75	7.30
Lime ..	..	..	..	0.45	1.19	3.41
Magnesia ..	..	..	..	1.28	0.50	0.76
Sulphur ..	..	..	..	0.23	—	0.46
Ferrous sulphide	..	..	..	—	0.27	—
Phosphorus ..	..	..	..	1.37	0.99	—
Copper ..	..	..	..	—	traces	—
Percentage of iron	..	..	..	50.96	42.84	47.66

ANALYSES OF REFINED IRON.

				Ebbw Vale (Noad).		Bromford (Dick).	France (Regnault).	
				Pig-iron.	Refined iron.	Refined iron.	Pig-iron.	Refined iron.
Carbon ..	Graphite			2.40	0.30	3.07	3.00	1.7
Silicon ..	..	..		2.54	0.32	0.63	4.50	0.5
Sulphur ..	..	..		0.22	0.18	0.16	—	—
Phosphorus ..	..	..		0.13	0.09	0.73	0.2	—
Manganese ..	..	..		0.86	0.24	trace	—	—
Insoluble matter	..			—	—	0.14	—	—
Iron ..	..	..		—	—	95.14	92.3	97.8

When the refining has been carried far enough the slag and metal together are tapped out into the cast-iron mould, *b* (Fig. 73). The slag (see the analyses above) floats on the metal, and remains fluid after the surface of the metal has become partially solidified; thus the slag can be tapped off into moulds placed at the lower end of the mould, *b*, while the plate of refined metal is the more rapidly cooled, and rendered also more or less hard and brittle by throwing a quantity of water over its surface.

The plate of fine metal, refined iron, plate metal, or simply "metal," as the product of the refinery is variously called, is from 1 in. to 3 in. thick, 12 in. wide, and from 12 ft. to 14 ft. long. It is grooved along its under side, and being brittle, can be easily broken up into pieces suitable for ready transport to the puddling furnace, where it is converted into malleable-iron. The metal presents a bright silvery-white fracture, the lower part of the slab affording a compact radiated or columnar structure, while the upper portion presents a dull and cellular appearance on fracture.

In this process of refining pig-iron, the loss of iron is somewhat greater and the consumption of fuel is about 20 per cent. in excess of what is required when the metal is taken in the fluid state direct from the blast furnace; but the average loss may be taken as equal to 10 or 11 per cent. of the weight of the pig-iron operated upon. The loss is greater in refining hot-blast than it is with cold-blast pig-iron, because the former contains a larger proportion of silicon, phosphorus, sulphur, manganese, etc.

In the ordinary melting-down process about 24 cwts. of good grey iron yield 1 ton of refined metal, the fuel consumption being about $2\frac{1}{2}$ cwts. of coke; and about 136,000 cub. ft. of blast per ton will be required for white iron, or 153,000 cub. ft. for grey iron. The weekly produce of a refinery with six tuyeres working upon grey iron ranges from 80 to 100 tons, and with white iron 150 to 160 tons. By running the fluid metal direct from the blast furnace into the refinery, about 22.3 cwts. of common forge, or 21.1 cwts. of good grey iron, will yield one ton of refined metal, the coke consumption being only about 2 cwts.; it will require only 94,000 cub. ft. of blast per ton of metal treated.

Dry Puddling.—The furnace employed in dry puddling is

little smaller than that used in the boiling process, and there is no tap-cinder or iron ore in the fettling or lining of the hearth. Formerly the bottom of the furnace was made simply by covering the iron plates with a layer of sand, which was then thinly glazed over with slag; but now the furnace bottom is lined with a 1 in. or $1\frac{1}{2}$ in. thickness of oxide of iron, formed by working a ball of scrap-iron in the strongly oxidising atmosphere of the furnace, the oxide of iron formed being spread evenly over the bottom whilst the furnace is still at a high temperature.

The charge of white or refined iron is placed around the sides of the furnace bed, leaving the centre empty until the metal begins to soften; then the damper is lowered to prevent the metal from becoming perfectly fluid. In its pasty condition the charge is drawn down into the centre of the hearth, where it is broken up and rabbled, so as to mix it with the oxide of iron already produced by the oxidation of the pasty iron, and with that now added to the charge in the form of hammer-scale. The rabbling continues from the running-down to the balling-up of the charge; a vigorous reaction ensues, the carbon and impurities becoming oxidised; in consequence carbonic oxide escapes, whilst the other impurities of the pig-iron are oxidised and largely enter the tap-cinder.

The progress of the decarburisation, "coming to nature" or "drying" of the charge, is indicated by the decreased fusibility of the metal, and other indications similar to those described under pig-boiling present themselves. This stage having been carried to the required degree, the damper is raised, and a higher temperature produced for the balling-up of the metal.

Owing to the smaller quantity of silicon and other impurities in the refined iron treated in dry puddling, the duration of the process is shorter than in pig-boiling, and the production of slag and the fuel consumption are less, and the oxidation is largely brought about directly by the air. Dry puddling is only economical in fuel so long as white or refined iron can be used, and the process is attended by a greater waste of iron than occurs in pig-boiling; whilst unless comparatively pure ores have been employed in the production of the pig-iron to be treated, the malleable-iron resulting from this process is also inferior in quality.

Best Yorkshire Iron.—Dry puddling and its preliminary refining are now almost abandoned in this country, except for the manufacture of best Yorkshire iron, for which they are still in use. Best Yorkshire iron is prepared from pig-iron made in furnaces supplied with a cold blast (cold-blast iron). This is then refined in a hearth, and the refined metal is then puddled. The puddling furnace is small, the charges worked being about 3 cwts., and the time occupied is about one hour. The furnace is provided with a small chamber under the chimney (the dandy), in which the iron is heated before it is passed on to the hearth of the furnace for puddling.

The high quality of best Yorkshire iron does not depend on the materials employed or the process used, so much as on the extreme care which is taken at every stage that no imperfect material shall pass. As this iron is about twice the price of ordinary bar iron the makers can afford to take special care in the manufacture.

CHAPTER XVIII.

FORGE MACHINERY:

THE term "forge" is applied in iron works to the department containing, besides the puddling furnaces, the shingling, blooming, and rolling machinery employed in the production of puddled blooms, slabs, or rough bars from the puddled ball which comes from the furnace.

The shingling or blooming machinery for treating the puddled balls consists of helves, or hammers, and of the puddling rolls or forge-train, which consists of two pairs of rolls, through which the shingled blooms are passed without any re-heating for conversion into slabs or puddled bars about 3 in. wide, $\frac{3}{4}$ in. thick, and 16 ft. long, or into plates averaging from 6 in. to 15 in. wide, if intended for rolling subsequently into plates or sheets.

The "mill" is a department in which the blooms, slabs, rough bars, etc., received from the forge, are cut up, piled, re-heated, again welded and finished by the mill-rolls into various classes of merchantable iron, such as merchant bars, rods, rails, plates, sheets, or other finished forms.

The shingling and blooming machinery consists of various types of squeezers, helves, and hammers. The helves and hammers act, of course, by the impact or of a falling weight, whereas the shingling by squeezers is effected by a direct compressive or squeezing force. The steam hammer is now generally used for shingling purposes, to the exclusion of the older forms of helve and squeezer.

Squeezers are either reciprocatory or rotary. The single alligator or crocodile squeezer has two broad flat jaws; the lower one (the anvil) is fixed, whilst the upper one forms one end of a heavy cast-iron lever pivoted on a gudgeon or axis forming the fulcrum of the machine. One extremity of the oscillating jaw is coupled by a connecting rod with a crank or its equivalent. In this manner the upper jaw, which has a toothed under surface, opens and closes upon the lower fixed jaw. The shingler introduces the hot puddled ball

into the open end of the jaws farthest away from the fulcrum, and gradually rolls the ball over towards the fulcrum of the crocodile after each stroke of the machine. At each stroke the bulk of the puddled ball is reduced by the escape of fluid cinder, which flows away from the mass over the sides of the lower jaw or anvil, and by the consolidation of the metal. Finally the compressed ball is formed into a slab or bloom about 5 in. in diameter and 18 in. long. At the extreme outer end of the jaws the movement is sufficiently great to permit of the bloom being placed on end, and compressed endwise, so as to shorten or upset the bloom, and square up the ragged ends. The bloom, when finished at the crocodile, is still sufficiently hot for introduction into the puddling

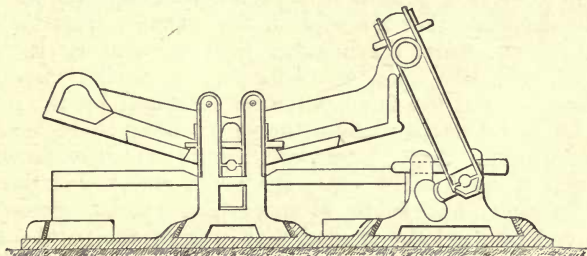


Fig. 74.—Double-acting Crocodile Squeezer, Front Elevation.

rolls for drawing down into puddled bars. The crocodile squeezer makes about 60 strokes per minute, and each ball receives about twenty or twenty-five compressions during its conversion into the puddled bloom. Whilst for heavy blooms squeezers are much more efficacious than hammers, for those dealt with from the puddling furnace the hammer is quite satisfactory. In the forge, therefore, hammers are now always used. Fig. 74 shows a double-acting crocodile squeezers.

Hammers of various classes are employed in the forge for shingling the puddled ball, and occasionally for the working of the finished iron, into the various classes of blooms, billets, forgings, etc., required for the rolling mills and by the engineer. In the older forges the tilt and helve hammers are still to be found, although in modern forges the steam hammer is more generally employed, even for shingling purposes.

The tilt hammer is not commonly used for shingling purposes, as it does not generally exceed 5 cwts. in weight, and works at a high speed, but it is still employed in some parts of Sweden for drawing down blooms into bars, etc. It consists of a wooden lever, strengthened with wrought-iron hoops, and having at one end a heavy sledge-hammer, whilst the cam which works the hammer operates at the opposite or tail end of the lever, the fulcrum being formed by the two arms of a trunnion ring resting on a vertical timber framework placed between the hammer-head and the cam, but nearer to the latter than to the former. As the cam, which is a revolving wheel with twelve or fourteen projecting teeth or wipes, revolves, the wipes press down the short end of the lever, and so raise the hammer-head until the lever is so far depressed that the wipe on the cam slips from the end of the lever, when the hammer then descends by its own weight, and falls upon the work on the anvil. The force and rapidity of the fall are further increased by the introduction of an elastic piece of timber or spring board beneath the short arm. As the cam revolves and the next tooth comes around, it repeats the same operation, and the strokes of the hammer thus follow in quick and regular succession. The end of the lever is shod with iron at the point where the wipes bear. The bottom anvil is of wrought-iron fitted into a heavier mass of cast-iron.

Helve or lifting hammers are of two types, and are made from 30 cwts. to 10 tons in weight; they are still used for shingling in forges where the steam-hammer has not yet been introduced. In one class of helve the cam acts upon the heavy cast-iron lever at one extremity, whilst the fulcrum is placed at the other extremity, constituting the nose or frontal helve, as illustrated in Fig. 75. In the nose or frontal helve, the arm or lever is lifted up as the cam revolves, and is then allowed to fall by its own weight upon the puddled ball placed on the anvil beneath. Into the head of the arm the wrought-iron hammer is dovetailed, and keyed so as to permit of ready removal for the renewal of the faces, as is frequently required. Such helves as are still in use in a few places in Staffordshire, etc., for shingling are from 5 to 6 tons in weight, and the cam, which is about 5 feet in diameter, and fixed upon a continuation of the fly-wheel shaft, has

five teeth or wipes, so that the helve makes five strokes for each revolution of the cam, in which manner the helve makes from 80 to 100 strokes per minute, and the maximum lift of the head is from 16 in. to 20 in.

The belly helve, owing to the cam being generally fixed beneath the floor level, and acting also between the head and the fulcrum of the machine, gives a greater space around the anvil for the manipulation of the puddled ball than the frontal helve.

Steam Hammers.—The steam hammer is now generally preferred to the helve for shingling purposes, since its blow can be regulated according to the work to be done, by throttling the escape of steam to the exhaust, whereby a cushion of steam is preserved beneath the piston of the hammer as it descends

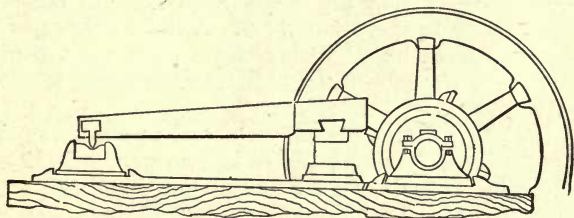


Fig. 75.—Nose or Frontal Helve, Front Elevation.

upon the work, thereby diminishing its velocity and the weight of its blow ; but with the helve the head is always lifted to the same height, and such control as this is impossible. Moreover, the heavy blows of the steam hammer consolidate the metal more quickly and expel the cinder more effectually because the work is done more quickly and more cheaply, while the bloom is still at a high temperature, and if desirable the hammer can be worked so slowly as to be practically a squeezer, so that the metal can be “humoured” in a way that is impossible with a helve hammer.

Steam hammers are somewhat differently constructed according to the special work to which they are to be applied. Thus the smaller hammers adapted to the forging and drawing down of bars generally consist of a single cast-iron standard, in front of which the piston and hammer-head descend on to the anvil. Supported upon the top of the standard is a vertical

steam cylinder of which the piston rod passes through a gland or stuffing box in the cylinder's lower cover, and is attached to a heavy block or tup which thus ascends and descends with the piston, as the steam is admitted to or escapes from the cylinder. The rotation of the piston and tup is prevented by planing a flat side upon the piston rod and making the stuffing box of a corresponding shape, or the tup is made to work in a guide on the face of the hammer standard. The cylinder is provided with suitable valves connected with levers, by small movements of which the workman can control readily both the ascent and descent of the hammer tup. These hammers are made so that the hammer tup and piston are lifted by the admission of steam beneath the piston, and then allowed to descend upon the work by opening the valve, and so allowing the steam from beneath the piston to escape freely to the atmosphere. A much more powerful hammer is formed by admitting steam upon the top of the piston during its descent, as well as exhausting the steam from the under side of the piston.

In the larger hammers of 30 cwts. and upwards the single standard of the hammer is replaced by two standards, between which the tup ascends and descends. For shingling purposes hammers in which the aggregate weight of the falling mass of tup, rod, and piston is from $1\frac{1}{2}$ to 3 tons are in most frequent use. Fig. 76 shows a double-acting steam hammer.

The foundations for steam hammers are required to be most substantial. They are usually formed first of a layer of concrete, or of concrete on wooden piles driven as far as possible into the earth; upon the concrete are placed cast-iron bed-plates of weights proportionate to the size of the hammer; or, in heavy hammers, it is usual to alternate heavy cast-iron plates with balks of oak timber arranged in various ways, and upon this foundation are finally fixed the heavy anvil-block or blocks, of cast-iron, into which the working bottom anvil block is fitted by a dovetail joint and wedges in the same manner as the top anvil or block is fixed in the tup of the hammer. The bottom anvil block for a 10-ton double-acting hammer weighs about 110 tons, whilst the superstructure of hammer and base plate of the same hammer weighs only about 80 tons.

Forge-train.—The rolls for converting the shingled bloom

of malleable-iron into puddled bar, or into merchant bars, etc., form part of the plant of the forge and mill departments respectively. The train consisting of two pairs of rolls, used in the forge, is known as the puddling rolls; whilst the train of two stands of rolls for the production of sections, plates, and other finished iron or steel, is fixed in the mill, and known as mill rolls.

The puddling rolls or forge-train consists of two pairs of cast-iron rolls placed in one line: The pair of rolls placed at the left of the train are known as the roughing rolls, and in the forge-train they are from 3 ft. 6 in. to 5 ft. long, and from 18 in. to 22 in. in diameter, with a series of oval, Gothic, or diamond-shaped grooves turned upon their surface. The first groove is roughened by cutting indentations upon its surface with a chisel, so that it may the better take hold of the shingled bloom when

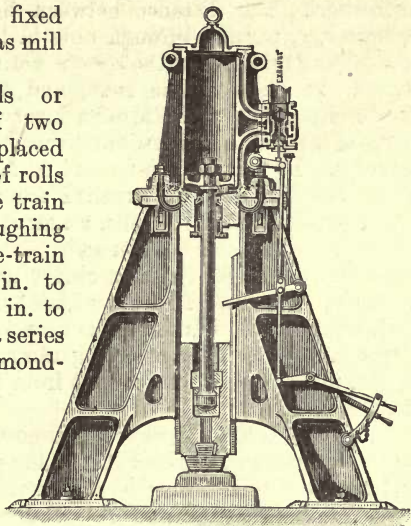


Fig. 76.—Double-acting Steam Hammer, Front Elevation.

it first enters between the rolls. The first two or three grooves of the roughing rolls are Gothic-shaped, whilst the others are diamond-shaped, and the depth of the grooves also diminishes from left to right along the rolls. The two rolls of each pair are placed one above the other in the same manner as the mill rolls (Fig. 77), and the necks or bearings of the rolls are supported upon brasses, in massive cast-iron housings or standards A (Figs. 77 and 78). The lower roll runs in a line with the driving-shaft of the engine; whilst between the engine and the mill is a pair of spur or helical toothed pinions B (Fig. 77), of the same diameter as the rolls, which pinions run in their own standards or housings D. The outer

end of the lower pinion is connected direct with the engine shaft, whilst the other end is coupled to the bottom roll by connecting spindles *b*, *b*, and coupling-boxes *a*, *a*, as illustrated in Figs. 77 and 78. The upper pinion is coupled in the same manner with the top roll, and is driven by the lower pinion ; so that the rolls like the pinions thus revolve in opposite directions. The distance between the rolls is adjusted by screws *s*, *s*, passing through nuts in the top of the housings, the lower extremity of the screws acting upon the top bearers *k*, on the neck of the rolls, and the screws are worked down either by hand, through levers upon the heads of the screws, or fed down automatically by an arrangement of gearing. To protect the necks and steps of the roll bearings from the cinder, etc., expelled from the metal during its roughing-down in these rolls, a narrow groove is often turned in both the top and bottom rolls, and a cinder-plate of sheet-iron inserted to prevent the cinder from passing towards the necks of the rolls. In front of the bottom roughing roll and extending for the full width between the housings is a serrated fore-plate or rest, for receiving the shingled bloom from the bogie, upon which it is brought from the squeezer or hammer to the rolls.

The connection between the engine and the bottom pinion of the forge-train, as also between the pinions and the rolls and between the rolls themselves, is made by breaking-pieces or spindles, *b* (Figs. 77 and 78), and coupling-boxes *a*, which are made somewhat weaker than the necks of the rolls, so that whenever the mill encounters any unusual resistance or sudden strain these spindles break before any serious damage can be done to the forge-train. The necks of the rolls project beyond the bearings in the housings, and have the same form as the end of the spindle *b*, whilst the coupling-boxes or wabblers *a* (Fig. 77) fit easily upon the projecting end of the roll, as also upon the end of the spindle. When the spindle with its two coupling-boxes has been placed between the two rolls or other necks to be coupled, the coupling-boxes already placed upon the spindle are moved half their length over the wabblers end of the roll or pinion, as the case may be, so as to connect the two ; whilst the slipping back of the boxes during the working of the mill is prevented by the introduction of wooden or iron stops, laid in the hollow of

the spindles and between the ends of the coupling-boxes; the stops are secured in position and prevented from falling out during the revolution of the rolls by twisting an iron wire or band around them and the spindle.

The finishing rolls of the forge-train are similar in their housings to the roughing rolls just described, but their grooves are flat channels, and form, when the pair of rolls are together, the required section for the puddled bar. The grooves diminish in depth from left to right, and those in the upper roll stand over those in the lower. In front of the bottom roll is a fore-plate or rest, and also guides for the easier insertion of the bloom from the roughing rolls into the grooves of the finishing rolls.

The puddle rolls receive the hot puddled blooms direct from the squeezer or hammer, and the blooms are first introduced into the largest groove at the extreme left of the roughing rolls. After passing through them the bloom is returned over the top of the rolls, to be again inserted from the front side into the next groove to the right, and so on in succession through the several grooves of the roughing rolls as required to produce the desired bloom. The bloom so obtained is passed onwards to the finishing rolls of the train, where it is passed in like manner successively through the several grooves or holes of this pair, until long flat bars with more or less ragged edges and a rough surface, and from 3 in. to 7 in. wide, and from $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. thick, according to requirements, constituting puddled bar, are produced. From this, merchant bar is prepared, as already described by the cutting up and piling of puddled bar, reheating it to a welding heat and again passing it through the rolls. If the puddled bars are intended for cutting up and piling into piles for the production of plates, then the width of the puddled bar is made from 7 in. to 15 in.

The forge rolls revolve at the rate of from fifty to eighty revolutions per minute, the quicker speeds being more general in Wales, whilst the slower speeds are more prevalent in Staffordshire and the Midlands. The rolls, as also their necks or bearings, are kept cool by running a continuous but regulated supply of water over them.

CHAPTER XIX.

THE MILL.

THE mill equipment includes the furnaces in which the metal has to be heated for rolling and the rolls. The mill rolls are employed for the production of finished iron from the puddled bar. The bar is cropped or cut up in suitable shears, and piled in various ways to form a parcel or packet, which is then inserted into a balling or reheating furnace for raising it to a welding heat, after which it is passed through the mill rolls to weld together the constituent bars of the pile, producing thereby No. 2 and higher grades of merchant iron, rods, bars, sections, etc., the quality depending upon the number of times the bars have been cut up, piled, reheated, and rewelded. The piles employed in the production of the heavier sections vary in size from 4 ft. 6 in. long and 12 in. square to 18 in. long and 3 in. square, but the latter are exceptional, such light sections being rolled from "billets," which are merely short lengths of square bars of a section and weight required to produce the finished product.

The mill rolls or mill train (Figs. 77 and 78), for rolling merchant iron, like the forge train, consists of two sets of rolls, of which the roughing or billeting rolls average about 6 ft. 6 in. in length and 22 in. in diameter, whilst the finishing rolls are somewhat smaller in diameter and shorter in length; but their length and diameter vary considerably in different works, being much influenced by local or other special requirements. The rolls run in bearings carried in housings as described for the puddling rolls, except that the finishing rolls in the mill are also provided with tightening and adjusting screws n (Fig. 79) for keeping them more accurately in position as the bearings wear down, in addition to the setting down screws s in the head of the housings for adjusting the distance apart of the rolls. The necks l of the rolls do not rest in continuous brass bearings, but bear upon four small brasses carried respectively in the bearers or riders k , k ,

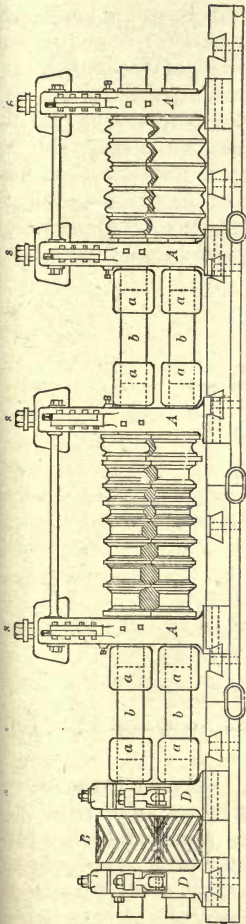


Fig. 77.—Mill Rolls for Rolling Sections, Rails, etc., Front Elevation.

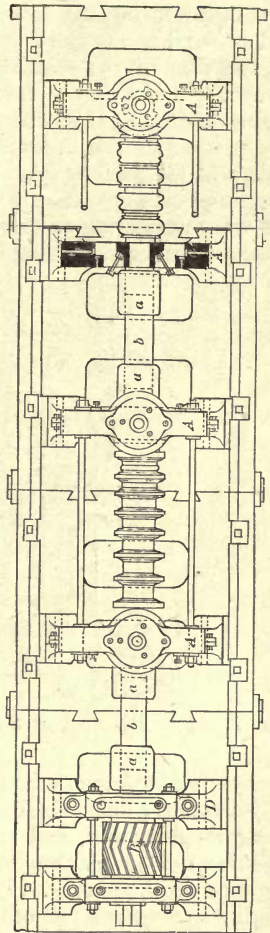


Fig. 78.—Mill Rolls with One Standard in Section, Plan.

and the side chocks m , the side brasses being adjusted by the set screws n . The top roll is carried by a bolster, k_1 , supported at each end from the top of the standard by the two bolts p , which pass through the rider k , and the side chocks, m ; or in other cases, instead of passing through the

top of the housing, the bolts *p* are on the outside of the housings and suspend the bearer *k* from two lugs cast for this purpose on the side of the standards. The power of the engine is transmitted through a claw-clutch or crab on the end of the engine shaft, and thence through a spindle to the lower pinion of a pair which run in their own standards, while the wabblers ends *a* of the pinions (Fig. 77) are connected by spindles and coupling-boxes or wabblers with the ends of the roughing rolls ; the other projecting or wabblers ends of the two roughing rolls being in like manner coupled by boxes and spindles with the

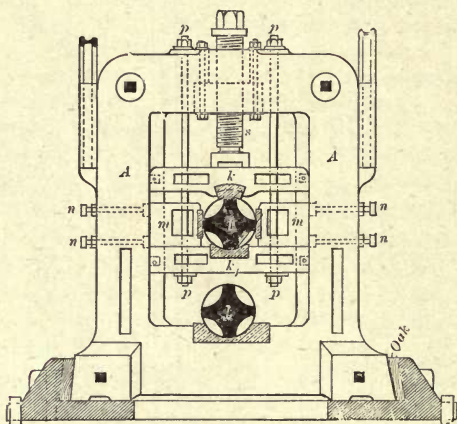


Fig. 79.—Roll Housing, or Standard for Mill Rolls, End Elevation.

near ends of the two finishing rolls ; or, as is sometimes done, only the lower finishing roll is connected by a spindle with the lower roughing roll, and motion is then imparted to the top finishing roll by gearing fixed on the outer projecting ends of the two finishing rolls. This latter method of driving from the lower roughing roll only has the advantage of permitting the use of larger or smaller roughing rolls, as may be desired, without interfering with the finishing rolls.

In rolling small and light sections, which are therefore whilst hot very flexible and difficult to keep from bending and twisting during the operation, it is usual to provide an apron or fore-plate in front of the rolls, as also guide jaws

for directing the work straight as it enters the rolls, in which manner much of the twisting is avoided, and the train so provided is hence known as a "guide train," and the iron produced therein as "guide iron."

In rolling sections, bars, etc., the bottom roll is always provided with "stripping-plates;" these are plates of iron resting at one end in a cross-bar supported by the roll standard, and at the other end upon the roll itself. They are shaped to fit into the several grooves of the rolls, and are also bevelled off at their lower edge so as to fit on the circumference of the roll, with their upper surface tangential to the surface of the roll. They thus act as chisels or wedges in clearing the bars from the grooves of the bottom roll, thus preventing "collaring," or wrapping of the bars around the bottom roll.

In two-high trains revolving constantly in one and the same direction it is, as already explained, necessary to return the work over the top roll from the back to the front of the rolls, after each pass of the work between the rolls; and thus much time and labour is lost, to overcome which either "three-high rolls" or mills that can be reversed at each passage of the work have been largely adopted for the mill-trains.

For lifting light work to the top of the upper roll in the two-high non-reversing mills, it is usually sufficient to receive it as it issues behind the rolls upon forked levers suspended from a travelling carriage above, and by which the workman raises the bar to the required level, so that the roller-man in front of the rolls may seize it with his tongs and draw it forward on to the fore-plate of the mill for insertion into the next hole of the rolls. Where heavy sections or plates are rolled, some two-high plate mills have movable fore-plates or feed-plates fitted to the mill, so that as the work issues from behind the rolls it is received on this plate, which is at once raised to the required level by a single-acting engine, or by an arrangement of levers worked either by hand or by power, or the table is elevated by an hydraulic cylinder and ram. The work thus elevated is drawn over the top rolls to the front side of the mill, ready for its reintroduction between the rolls.

Reversing Rolls.—In the case of reversing mills the reversal is effected either by reversing the engine itself, as introduced by Mr. Ramsbottom for the rolling of rails, etc.,

or by the introduction of hydraulic, friction, or other clutches and gearing on the engine shaft, whereby the rotation of the rolls is reversed whilst the engine continues its revolutions always in the same direction.

Three-high rolls consist of roughing and finishing rolls, each of which is a combination of three rolls in its own pair of housings. With three-high rolls the mill is usually driven

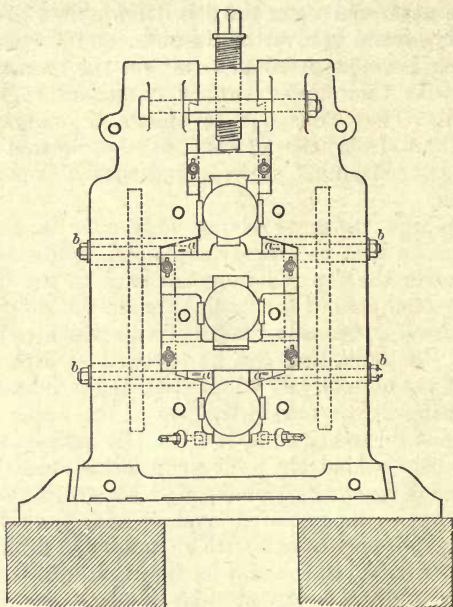


Fig. 80.—Housing for Three-high Rolls, End Elevation.

from the middle roll, although under special circumstances it may be driven from the lower one. Thus the rolls are driven through three pinions, the wabblers ends of the pinions being coupled as before by spindles and coupling-boxes with the ends of the three rolls; and the middle roll therefore revolves forward with the lower one, and backwards with the upper one, or *vice versa*, according to the direction of rotation of the middle roll, so that the work thus passes backwards and forwards alternately through the grooves or

holes between the middle and bottom rolls, and between the middle and upper rolls respectively. The work, as it issues from the grooves in the lower rolls, is received and lifted in the manner already described to the level of the holes between the middle and upper roll, after passing through which the bar is received on the other side by a corresponding arrangement, and immediately lowered to the level of the lower pair of rolls.

In three-high mills various mechanical arrangements are made for adjusting the distance of the top and bottom roll from the middle one. In two-high mills, the top roll is movable for the purpose of adjustment, but in the three-high system either the middle roll may be fixed and the top and

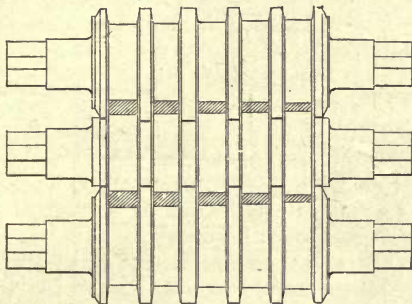


Fig. 81.—Three-high Rolls for Merchant Iron.

bottom rolls run in adjustable bearings, or, as in Fig. 80, the bottom roll is fixed, and the middle and top rolls are carried in adjustable bearings.

In most American three-high trains for merchant iron, the top and bottom rolls are grooved (*see* Fig. 81), and the middle roll has the collars turned upon it. This plan requires shorter rolls for the same number of passes, and obviates turning over the bar after each pass, the grooves opening alternately upwards and downwards, so that the fin formed in the top groove in the upper pass is smoothed down by the solid bottom of the groove in the upper pass. An objection to the three-high mills is the necessity of providing between the middle and top rolls suspended and balanced stripping-plates for turning the work out of the grooves as it issues from the rolls.

Plate Mill.—The general arrangement of a plate mill is the same as that of the ordinary mill train, except that the rolls are plain cylinders of uniform diameter, and that the top roughing roll is balanced by counter-weights as

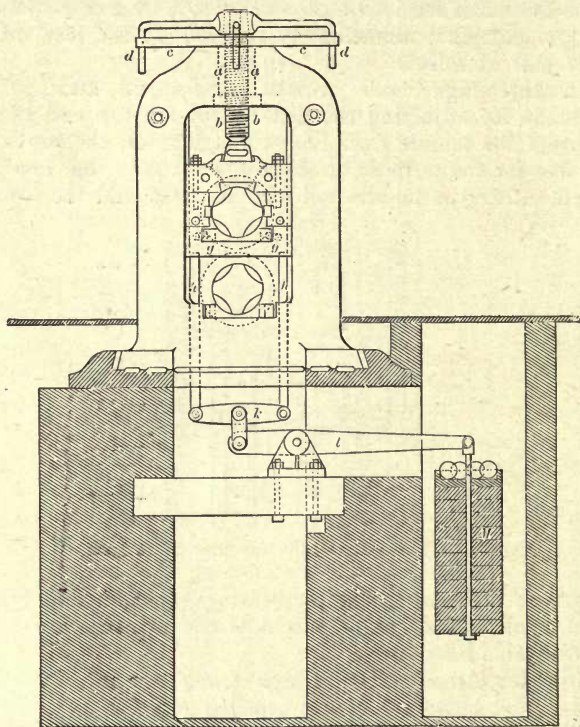


Fig. 82.—Plate Mill Housing, showing Balance Weights for Top Roughing-roll, End Elevation.

in Fig. 82, whilst the top finishing roll runs freely, being revolved only by the friction of the work passing between it and the bottom roll. The plate mill has two pairs of rolls varying in different mills from 20 in. to 36 in. in diameter and from 4 ft. to 9 ft. long. The roughing rolls are grain-roll—that is, cast from tough cast-iron, not chilled on the surface

—whilst the finishing rolls are chilled castings, the depth of chill varying between $\frac{1}{2}$ in. and $1\frac{1}{4}$ in. All the rolls run in brass bearings and are carried in housings, in the top of which are fitted nuts *a*, and setting-down screws *b*. When the setting-down screws are moved by hand, a large hand-wheel *d* is fixed to the head of each screw, the degree of rotation being indicated by a pointer and a graduated ring *c* fixed on each housing, so that the workman may see that both screws are set down to the same degree, so giving the same thickness to both edges of the plate as it passes between the rolls. Spur and bevel gearing governed by a self-acting arrangement for feeding down uniformly both screws at once is applied to the larger mills, this self-acting motion being necessary when tapered plates are being rolled, in order that the rolls may be uniformly and gradually fed down to give the desired decrease in thickness from end to end of the plate as it passes between the rolls. The top roughing roll rests in a bolster *g*, supported upon bars *h*, which are connected with a system of levers *k*, *l*, and balance weights, *m* (Fig. 82), suspended beneath the bed-plate or foundation of the rolls. These balance weights suffice to lift the top roll as the feed-screws are turned back, and so keep it constantly in contact with its top bearing, thus preventing the fall of the top roll on to the bottom roll as the bloom or slab leaves the rolls after each passage between them. A pile, bloom, or slab of 4 in., 8 in., or 10 in. or upwards in thickness can be introduced between the rolls. The finishing rolls have generally much less work put upon them than the roughing rolls; they usually reduce the plate by only a fraction of an inch, but they take out the buckling and any irregularities of thickness from the rough plate. The top finishing roll runs loose in its bearings and revolves solely by the friction of the plate passing beneath it, and the upper roll thus drops down through the thickness of the plate on to the lower roll as the plate leaves the rolls after each pass. The distance apart of the rolls is diminished at each pass by screwing down the feed-screws, and in non-reversing mills the plate is lifted by a movable table arrangement and passed over the top of the rolls to the front side, to be again inserted between the rolls.

To overcome this loss of labour and time reversing mills have been adopted. The plates pass between the rolls from

front to back, and are received there on a horse or platform inclined towards the rolls, and fitted with friction rollers, over which the plate moves. When the mill is reversed the plate is easily pushed forward with tongs or bars down the horse and into the rolls; on the front side of the rolls it is received on a bogie, which runs out with the end of the plate as it issues from the mill. The rolls are reversed and the screws set down at each pass, until the desired thinness has been attained, upon which the plate is conveyed to the mill floor near to the shears, where it is laid down to cool, and straighten if necessary.

In plate-mills and two-high mills generally the circumference of the top roll in contact with the metal is made slightly larger than the bottom roll, so that the upper surface of the metal is extended a little more than the under surface. Thus the leading end of the plate tends to curve downwards as it leaves the rolls, and collaring around the top roll is prevented. Stripping-plates are fitted to prevent collaring around the bottom roll.

The metal extends in rolling almost wholly in the direction of its length; hence the bloom, etc. is first passed between the roughing rolls in the direction of its breadth so as to extend it to the full width required.

The ends of a rolled plate are cut, as may be necessary, to reduce the plate to the requisite dimensions.

Iron plates formed from piles built up in a special manner are passed through the roughing rolls in the directions of their length and breadth alternately, until the full width has been attained, after which the rolling is continued entirely in the direction of length. The object is to get the strengths of the plate in the two directions as uniform as possible.

Sheet mills resemble the plate mills, except that the rolls and mechanism are lighter. The sheet mills of Birmingham and of South Wales have rolls from 18 in. to 22 in. in diameter and from 3 ft. to 6 ft. long, running at from thirty to thirty-five revolutions per minute. For producing the larger sheets the billets are about $1\frac{1}{4}$ in. thick, and two of them are usually rolled together, passing between the rolls crosswise from the front side and then being returned by the back-hand over the top of the rolls to the front side, whilst the screws are set down to reduce the space between the rolls after each passage

of the work. Thus the plates are reduced to about $\frac{1}{8}$ -in. thick, and then they are placed one upon the other and passed together through the rolls for a few times, until finally two sheets, each about 3 ft. 6 in. wide and 5 ft. long are produced. The sheets are then annealed at a red-heat and, after reheating, are again returned to the rolls in pairs and further extended; if the sheets are to be very thin each one is again doubled upon itself crosswise, reheated, and again rolled. Then the sheets are put on one side to cool, after which they are sheared to size, again annealed, and finally made into bundles for sale.

Annealing.—The annealing is effected by placing the sheets in wrought-iron or steel annealing pots or boxes, which, when filled, are run into a reverberatory furnace and allowed to remain there for about twenty-four hours. Large annealing pots hold 18 tons of sheets, each 10 ft. long. They are charged by piling up the sheets on a base-plate, over which the inverted pot is dropped, the joint of the cover and base-plate being luted with clay. The whole is then inserted into the furnace, and heated as above; the pot requires about four days to cool down after withdrawal from the furnace. Very much smaller annealing pots than the above are in use in South Wales.

Universal Mills.—The so-called universal or Belgian mill for rolling plates and bars has two horizontal rolls *a* running in standards, and geared together; in addition a pair of vertical rolls *b, b* (Fig. 83) work in front of the horizontal rolls. The top horizontal roll is balanced by counter-weights *c*, after the manner of the plate-mill, so as to keep the roll against its top bearing. The distance between the rolls is regulated by screws rotated by two hand-wheels; or the screws are connected by gearing with a shaft *e*, actuated by one wheel *d*, which is rotated either by hand or by steam power. The vertical rolls work upon slides, and can be moved towards each other or apart from one another by a right- and left-handed screw *k*, working in nuts carried upon the bearings of the two vertical rolls, and actuated by means of the worm-gearing *h*, moved by a hand-wheel *m*, which is under control of the workman. The vertical rolls are rotated from the driving pinion, *g*, of the mill through spur and bevel gearing so arranged that the bevel wheels slide along their shaft, and thus follow the lateral movement of the rolls as these are either separated or brought closer together. The work as it passes through these rolls

is compressed on the edge by the vertical rolls and on the flat between the horizontal rolls; so that a mill of this class may be employed for the production of a considerable variety of sections of flat bars by simply adjusting the horizontal and

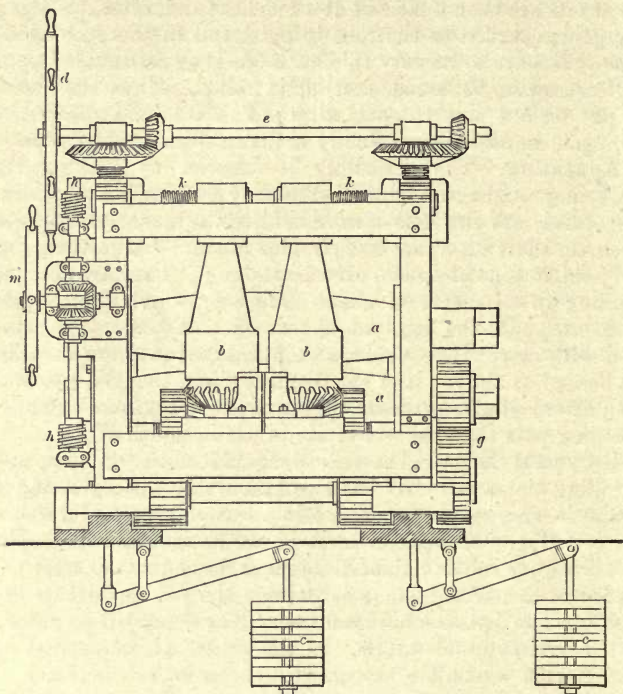


Fig 83.—Universal or Belgian Rolling Mill.

vertical rolls to the thickness and width respectively of the bars required.

Speed, etc., Mills.—The size and speed of mills vary with the work to be done. Reversing mills for rolling heavy plates with rolls of from 20 in. to 36 in. in diameter make only 25 to 30 revolutions per minute, the smaller mills for merchant bars or guide iron, with rolls from 12 in. to 18 in. in diameter, generally run at the rate of from 80 to 125 revolutions per minute; the

still smaller mills, such as those for rolling billets into wire, with rolls from 8 in. to 12 in. in diameter, run at from 250 to 500 revolutions per minute. The roughing rolls in reversing mills for rolling iron rails, and having rolls from 20 in. to 24 in. in diameter, run at about 30 revolutions per minute, the speed being much higher when the mill is non-reversing. Mills rolling steel usually run 25 per cent. or 30 per cent. faster than the corresponding mills working upon iron, and owing to the much lower temperature to which steel is heated, more power is required for rolling a given section in steel than in iron. It may be noted that in rolling rails, when the rail leaves the finishing rolls it is carried along upon a series of five power-operated rollers in the floor to a circular saw 8 ft. in diameter, where the ends are cut square and to the exact length. After the rails have become cold, they are straightened in a horizontal straightening press, and then passed on for drilling at each end under double-drilling machines, as required for the fish-bolts.

The usual time occupied in England in rolling a double length of steel rail with six roughing and five finishing passes is a little more than two minutes. In the American mills, driven feed-rollers like those just mentioned for receiving the rail from the mills are employed both in front and in the rear of the rolls wherever heavy work is manipulated.

The slitting mill for the production of "slit" or "nail rods" consists of a pair of rolls, housed in the usual manner, but made to act as a compound shearing machine, for which purpose collars acting as circular cutters are turned upon the rolls, or separate steel collars or discs are fitted upon a spindle or arbor with stops between them. The discs on the upper roll falling into the space or groove between the collars on the lower roll, but leaving sufficient space for the thickness of the metal. Flat bars are divided or cut during their passage through the rolls, and are delivered at the rear of the mill as a series of bent and twisted strips or rods of rectangular section, requiring to be straightened by hand and made into bundles, when they are ready for sale to the nail forgers. The bars, on entering the slitting mill, are steadied by guides, and the cutters are cooled by water continually running over them.

Mill Engines.—Rolling-mill engines vary considerably in

type and power; they are made direct-acting, high-pressure, either non-condensing, condensing, or compound, while both vertical and horizontal types are employed; but non-reversing, high-pressure, non-condensing engines with heavy fly-wheels are usually adopted for the smaller mills rolling merchant and guide iron in two-high or three-high mills; whilst for the heavy mills producing iron and steel plates, rails, heavy angles, sections, and the like, reversing mills are the more usual.

Reversing mills are usually driven by horizontal engines either of the high-pressure or of the compound type; such engines being fitted with either friction clutches, hydraulic clutches, differential gear, etc., the rolls can be reversed whilst the engine moves constantly in the same direction; or, as is more general, the engine itself for reversing mills is reversed at each pass of the work between the rolls, according to the plan introduced by Mr. Ramsbottom, and hence generally known as the Ramsbottom reversing mill engine, but it is altered or modified to suit the special conditions of different mills. Reversing engines are now made also somewhat extensively upon the compound type.

Piling Bars.—The method observed in building up or piling the bars and slabs of malleable-iron into packets or piles for reheating and welding together into a solid mass varies for every class and quality of work. For the production of No. 2 merchant iron the bars of No. 1 are cut up into lengths, and the pieces so obtained are piled into a stack some 6 in. or 8 in. square, from 30 in. to 40 in. long, and about 4 cwts. in weight. The joints of the several bars do not fall one above the other, but always cross or break joint. The pile so formed is held together by an iron hoop, and after being raised to a welding heat in the reheating or balling furnace, the pile is passed through grooved rolls in the manner described; or the welding together may be effected by hammering and subsequently drawing the hammered bloom into bars by means of a bar or guide-mill. For smaller bars the piles of about 100 lbs. each are only about 18 in. long and from 3 in. to 4 in. square, formed from flat bars about $\frac{3}{4}$ in. thick; but billets are more generally used for these smaller sizes.

For making iron plates the pile is formed by placing the bars in layers, each layer crossing the underneath one; the

top layer is covered like the bottom with a slab about $1\frac{1}{2}$ in. in thickness, and of a length and width suitable to the dimensions of the particular plate which it is designed to produce. Scrap and crop-ends are also built up along with the puddled bar in these piles.

For iron rails, about 18 or 20 pieces of puddled bar, each about 3 in. wide and $\frac{5}{8}$ in. thick, are arranged along with scrap-iron in the middle of the pile, while the top and bottom iron slabs are formed either of a plate of No. 2 iron from 6 in. to 7 in. wide and 1 in. thick, or of a puddled bloom which has been already doubled over upon itself, and previously rewelded. In rolling such a pile it must be so passed through the various holes of the rolls that these top and bottom plates are eventually rolled into the two heads of the rail.

For producing small round or square bars of merchant iron, the piles, after heating and hammering or rolling into square bars of $1\frac{1}{2}$ in. or 2 in. square, are cut under the cropping shears into billets of from 12 in. to 24 in. in length, and these billets are afterwards reheated and then rolled in the finishing rolls into small bars.

It is usual to form the top and bottom members of piles of single bars or slabs, because butt joints unless covered by other bars or plates do not weld properly. Thus, in piles for rails the top and bottom layers were formerly made up of slabs produced by the doubling over and welding together under the hammer of two or more puddled blooms, without the same having been previously rolled into bars in the puddling mill; but the hammered blooms so produced were reheated and rolled into the desired slabs. The ends of the bars, also because of the difficulty of welding, should be cut square, and the bars should be as free as possible from scale, dirt, rust, or other foreign matters which interfere with the welding, and consequently with the homogeneity of the finished bar. The piles, as formerly made in South Wales, for rolling into rails weigh about 15 cwts. each, and four of these are placed at one time into the reheating furnace, and afterwards rolled into blooms, which are then again reheated, and again passed to the mill. In nine passes through the rolls such blooms become finished rails ready for cutting to length, and subsequently drilling or punching for the fish-plate bolts.

Shearing the Bars.—The crop-ends of rails, angles, heavy sections, bars, etc., are cut off immediately the work leaves the rolls, the metal being still hot. The rail is drawn from the rolls to the front of a circular saw of from 4 ft. to 8 ft in diameter, running at the rate of from 800 to 1,200 revolutions per minute. The saw is carried in a swinging frame

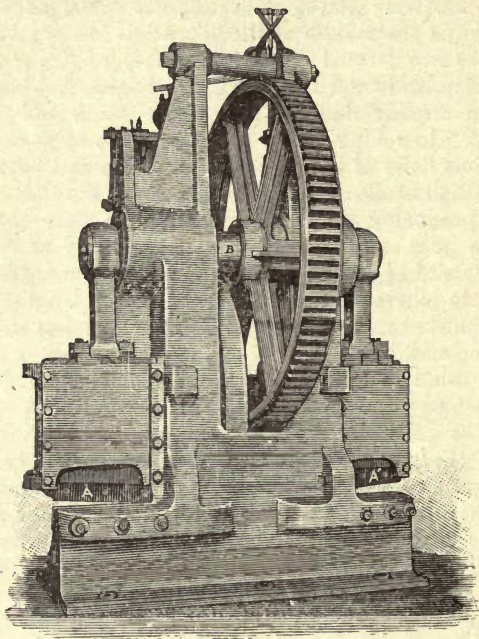


Fig. 84.—Shears for Cutting up Puddled Bars and Slabs.

which can be moved out towards the work by a rack and pinion arrangement controlled by the workman, which thus, amid a shower of sparks, rapidly cuts across the work, leaving the ends comparatively clean and square.

Puddled bars (Fig. 84) are also generally sheared hot with crocodile shears into lengths suitable for piling, etc., and these shears are likewise employed for cutting up the bars that are not cut up by the hot saws, as also for cutting off the rough or

crop-ends of puddled, finished, or other bars. Occasionally, for dressing the sides and edges of plates and shearing them to size, are used larger and broader-faced guillotine shears (Figs. 85 and 86). For the smallest and lightest plates or sheets the crocodile or alligator shears are still in use.

The crocodile, cropping, or alligator shears—three names for the same tool—has two jaws, the lower, *D* (Fig. 86), of

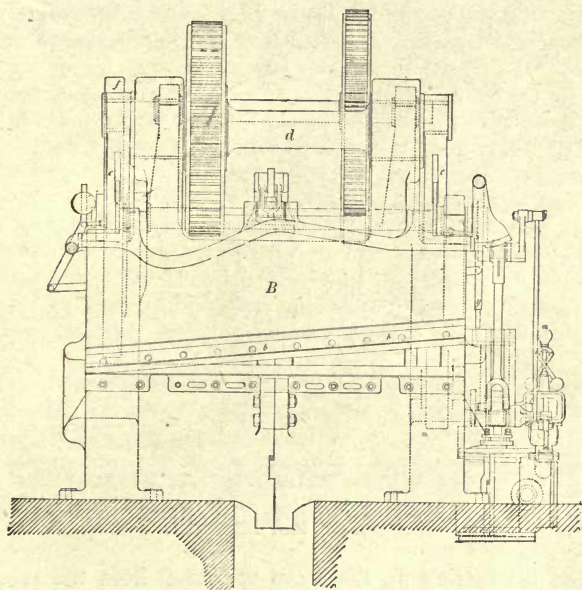


Fig. 85.—Plate Shearing Machine, Front Elevation.

which is fixed, and forms part of the cast-iron foundation or is secured to it, whilst the other jaw *E* oscillates on a pin passing through the jaw, and supported in bearings on the casting of the lower jaw. The upper jaw *E* has the form of a heavy straight or bent lever, one end of which is fitted with a blade *F* of steel, hardened on the edge to act as the cutter, whilst the end of the lever on the opposite side of the bearing is coupled by a connecting rod *G*, with a crank *H*, or with an eccentric. With the heavier shears it is usual

to derive the power from a small independent engine, upon whose shaft is a crank which is coupled by a connecting rod with the end of the moving jaw of the shears. The lower jaw also has a cutting edge of hardened steel, which works opposite to the blade on the fixed jaw, and these knives are readily replaced as they wear out. Fig. 86 shows a crocodile shears as applied to a powerful plate shears, where it is em-

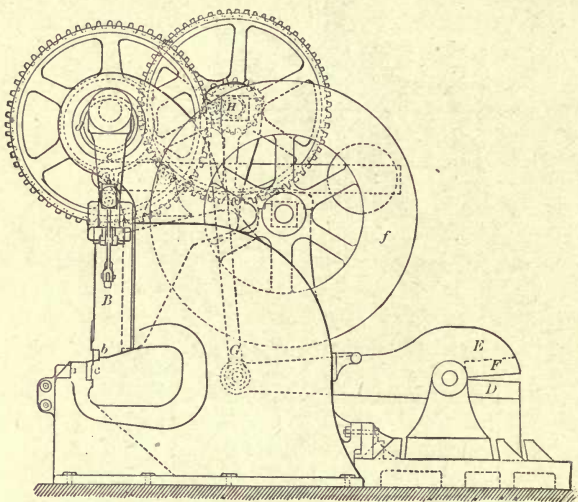


Fig. 86.—Plate Shearing Machine, with Crocodile Scrap Shears Attached, End Elevation.

ployed for cutting up the scrap produced from the shearing of plates, etc.

A form of powerful guillotine shears which has replaced somewhat the older crocodile shears, is represented in Fig. 85. This machine cuts on each side of the centre, having two pairs of blades, *A*, *A*¹, driven from cranks at either extremity of the same shaft, *B*, exactly in the manner of the ordinary shearing machine.

The shearing machine shown by Figs. 85 and 86 is employed for shearing heavy plates. It has a cast-iron framework, made in halves and bolted together. On the face of the standards, and working upon prepared surfaces, is the

apron or slide B, in the lower edge of which is fitted the steel-faced cutter *b*. The lower cutting edge makes an acute angle with the horizontal lower cutter *c* (Fig. 86) carried by the fixed foundation. Across the front of the machine, and working in brass bushed bearings, is a steel shaft *d*, upon which are forged two eccentrics, connected by powerful straps and links *e* with the top of the slide, which thus ascends and descends as the shaft revolves. At one end of the machine is an engine with a heavy fly-wheel *f*, and the power is transmitted between the engine shaft and the eccentric shaft *d* through heavy spur or helical gearing, as shown. The slide or apron B is fitted with a stop motion worked by the handle *y* so as to prevent the descent of the slide, whilst a heavy plate is being moved forward and properly set after the last cut. Such a machine can shear through cold iron plates $1\frac{1}{2}$ in. thick; the slide is from 7 ft. to 11 ft. long, and the inner faces of the two standards are from 5 ft. to 9 ft. apart.

Guillotine shears of this type, but very narrow across the face—that is, between the sides of the machine—are used for cutting up hot steel ingots or blooms of from 3 in. to 10 in. square, into the lengths required for rolling into bars, etc.

Reheating Furnaces.—The furnaces are known as heating or reheating furnaces. They are of several kinds: (1) open fire, as used in conjunction with the finery; (2) the hollow fire, as employed in South Wales for reheating the piles or stamps; (3) the reverberatory furnace or mill furnace fired with coal as usually constructed for mill purposes for reheating iron or steel for the hammers or rolls; (4) gas fired furnaces.

The forge reverberatory, or balling furnace, is generally arranged to burn raw coal or other solid fuels upon its own grate-bars; whilst the reheating furnaces for the mills and forging hammers are frequently replaced by furnaces burning gaseous fuel.

The reheating, mill, or balling furnace, adapted to the consumption of raw fuel direct upon its own grate, resembles externally an ordinary puddling furnace. It is supported externally (*see* Fig. 87) by cast-iron plates and buck-staves *a* secured from side to side and from end to end by wrought-iron tie-rods passing over the top and secured to the plates by nuts on the screwed ends of the tie-rods. The balling

furnace has a smaller area of grate-bars than the puddling furnace in proportion to the area of its bed ; the chimney *b* is also a little higher. The furnace bottom is formed of sand, oxide of iron, fire clay, or basic slag, on the top of a fire-brick lining. This type of furnace is employed more particularly in iron works for raising to a welding heat the piles of puddled bar or the higher grades of malleable-iron, previous to the rewelding of the same under the hammer, or in the mill rolls.

Balling furnaces as used in the South Wales forges have the hearth bottom made of cast-iron plates fixed about 14 in. below the working door, and upon this is laid a course of

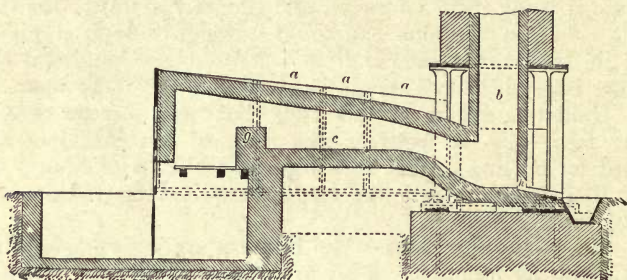


Fig. 87.—Reheating or Balling Furnace, Sectional Elevation.

fire-bricks upon which the working bottom is made by well ramming in sand in a moist state. The bottom or bed *c* slopes uniformly from the working door *d* (Fig. 87) to the back of the hearth, as also from the fire-bridge *g* to the stack *b*. The fire-bridge is built about 9 in. wide, and reaches to within about 14 in. of the roof, and the chimney or flue-end of the hearth is rounded off, and slopes, as shown (Fig. 87), towards the bottom of the stack. The cinder from the hearth thus flows along this flue to the tap-hole *h* at the base of the stack, and the tap-hole is prevented from closing up by the cooling and solidification of the slag or cinder within it by keeping a small fire constantly burning in front of it. The stoking-hole *k* is closed or stopped after firing by introducing lumps of coal into the opening, and then throwing a shovelful of coal slack over them just as is done with the puddling

furnace, whilst the draught is maintained and regulated to the requirements of the furnace by a stack, upon the top of which is a damper suspended from one end of a lever, from the other end of which hangs a rod reaching to the floor level. The height, as given above, of the roof from the bed of the furnace is adapted to the production of merchant iron of ordinary sizes, but for the heating of large slabs or forgings the roof may be raised, and the size of the doors increased considerably. In some furnaces, also, the cast-iron bed-plates are not introduced, in which case the sand bottom is prepared by ramming sand into a bottom of rubble masonry.

Gas furnaces are very largely used for reheating. They are usually of what is called the Siemens new type, in which there are only two regenerators—those for air, part of the products of combustion being sent through the gas producer, which is attached to the furnace. The gas enters and the products of combustion are drawn off at the same side. These and the other types of gas furnace will be fully described in the companion volume on “Steel.”

The workman, or “baller,” introduces the charges of piles into the balling furnace with the assistance of a heavy bar called a “peeler.” The flattened end of the peeler rests during the time of charging upon the sill of the furnace door, where the smaller piles are placed upon it; in dealing with heavier packets the peeler, with the pile upon it, is carried upon a bogie, which delivers it at the height of the furnace door. The peeler with its pile is pushed into the furnace, and the peeler is withdrawn, leaving the pile standing across the furnace parallel with the fire-bridge. For making merchant bars, four such piles are inserted into the furnace at one charging, care being taken not to disturb the arrangement of the bars. The charge is called a “heat,” and instead of four piles making up the heat, sixteen or eighteen smaller piles are frequently introduced in one heat. When the charging is completed, the door is lowered into position, and a shovelful of coal is thrown around it to prevent the admission of air. The temperature of the furnace is then raised by cleaning the grate-bars, adding more fuel through the stoking door, re-stopping the latter with coal, and then raising the chimney damper. In this manner large piles will attain to a welding heat in about one hour, and small

ones in thirty minutes ; they are withdrawn from the furnace with tongs and drawn forward on to a bogie in front of the door, which is run rapidly to the rolls, through which the dripping pile is at once passed. When all the piles have been withdrawn, the furnace bottom is usually slightly repaired by introducing a little sand, and then all is ready for the introduction of another heat. The withdrawal of the charge and repair of the bottom usually occupy from fifteen to twenty minutes.

During reheating, piles or ingots are moved about slightly to facilitate more rapid and uniform heating over the whole surface of the mass. As the mass approaches a welding heat the iron rapidly oxidises and scales ; the scale falls to the bottom of the furnace, where it combines with the silica or sand of the bottom with the production of a readily fusible slag or cinder, which flows away freely to the bottom of the stack, subsequently escaping through the tap-hole. The flue-cinder, or mill furnace slag, thus produced is essentially a ferrous silicate, containing from 50 per cent. to 60 per cent. of ferrous oxide, representing from 40 per cent. to 45 per cent. of metallic iron, the other constituents of the cinder being about 30 per cent of silica, with small percentages of ferric oxide, manganous oxide, alumina, lime, magnesia, sulphur, and phosphoric anhydride.

The consumption of coal in the production of No. 2 merchant iron from the ore, including that consumed in the calcination and smelting of the ore, the puddling of the pig-iron, and the reheating for rolling into No 2 quality of iron, is, roughly, about four times the weight of the bars produced ; and there is an additional consumption of from 9 cwts. to 10 cwts. of coal per ton for each additional piling and reheating necessary for the production of each higher grade of merchantable iron ; so that to make treble-best iron nearly 6 tons of coal are consumed per ton of bars.

The yield of merchantable iron per ton of pig-iron treated differs with the locality, the quality of the pig, the skill of the workman, and the quality of iron produced, or the number of separate pilings and reheatings to which it has been submitted ; but the average loss in the Staffordshire district is about 25 per cent., and in South Wales it is somewhat greater. Thus the loss in the Dudley district of Staffordshire

between the pig-iron treated and the puddled bars produced is about 10 per cent. or, more accurately, 24 cwts. of pig-iron usually yield 22 cwts. of puddled bars, while $22\frac{1}{2}$ cwts. of the latter are required to produce a ton of merchant bar.

In the gas furnace the temperature is more under control, and there is a greater purity of flame upon the hearth than is possible in furnaces consuming raw coal upon the ordinary grate-bars. Further, an oxidising, neutral, or reducing atmosphere can be maintained in the heating chamber of the furnace according as more or less atmospheric air is admitted for the combustion of the producer gases, and the loss of metal from oxidation is thereby diminished. This economy in the reheating of $1\frac{1}{4}$ -in. iron billets for the production of iron wire has amounted to about 5 per cent. In the gas reheating furnace the loss from oxidation does not exceed 2.5 per cent. of the metal charged, but with the ordinary coal furnace the loss is nearly 7 per cent. With steel, however, the direct economy is less, since the temperatures employed are lower and the oxidation and waste are therefore less active, whether coal or gas furnaces be employed. There is a total absence of smoke in working the gas furnace.

The use of the gas-producer instead of the ordinary grate permits of the consumption of inferior classes of fuel, such as coal slack, anthracite culm, and every variety of bituminous or semi-bituminous coals, lignites, peat, air-dried wood, etc. The gas-producer means a saving in the fuel consumption, and a more uniform heat. The contact of the fuel with the highly heated lining of the furnace is prevented, and therefore less repairs and longer campaigns are possible.

CHAPTER XX.

USEFUL TABLES, ETC.

*TABLE OF ATOMIC WEIGHTS.

<i>Element.</i>			<i>O = 16</i>	<i>Approx.</i>	<i>Element.</i>			<i>O = 16</i>	<i>Approx.</i>
Aluminium	Al	27.1		27	Manganese	Mn	55.0		55
Antimony	Sb	120.2		120	Mercury	Hg	200.0		200
Arsenic	As	75.0		75	Molybdenum	Mo	96.0		96
Barium	Ba	137.4		137	Nickel	Ni	58.7		58½
Bismuth	Bi	208.5		208½	Nitrogen	N	14.04		14
Bromine	Br	79.96		80	Phosphorus	P	31.0		31
Cadmium	Cd	112.4		112	Platinum	Pt	194.8		194½
Calcium	Ca	40.1		40	Potassium	K	39.15		39
Carbon	C	12.0		12	Silicon	Si	28.4		28
Chlorine	Cl	35.45		35½	Silver	Ag	107.93		108
Chromium	Cr	52.1		52	Sodium	Na	23.05		23
Cobalt	Co	59.0		59	Strontium	Sr	87.6		87½
Copper	Cu	63.6		63½	Sulphur	S	32.06		32
Fluorine	F	19.0		19	Tin	Sn	119.0		119
Gold	Au	197.2		197	Titanium	Ti	48.1		48
Hydrogen	H	1.008		1	Tungsten	W	184.0		184
Iodine	I	126.85		126½	Uranium	U	238.5		238½
Iron	Fe	55.9		56	Vanadium	V	51.2		51
Lead	Pb	206.9		207	Zinc	Zn	65.4		65
Magnesium	Mg	24.36		24					

For all metallurgical calculations only the approximate atomic weights need be taken.

Problem I.—From the formula of a substance to find its molecular weight and percentage composition.

Solution.—1. Write down the formula. 2. Multiply the atomic weights by the number of atoms present. 3. Add the resulting numbers. 4. From this molecular weight find the proportion of each element in 100 parts.

Example.—Find the percentage composition of ferrous carbonate.

Formula is FeCO_3 . $\therefore \text{Fe} = 56 \times 1 = 56 \therefore \% = 56 \times 100 \div 116 = 48.28$

$\text{C} = 12 \times 1 = 12 \therefore \% = 12 \times 100 \div 116 = 10.37$

$\text{O}_3 = 16 \times 3 = 48 \therefore \% = 48 \times 100 \div 116 = 41.35$

\therefore Molecular weight = 116.

100.00

Problem II.—From the percentage composition of a substance find its empirical formula.

Solution.—1. Divide the percentage of each element by its atomic weight. 2. Divide each quotient by the lowest number. 3. Allocate the factors.

Example.—Find the formula of a substance containing the following percentages :

	At. wt.	Ratio.
Sulphur (S) = $22.53 \div 32 = 0.704 = .704 \times 1 = 1$		
Sodium (Na) = $32.39 \div 23 = 1.408 = .704 \times 2 = 2$		
Oxygen (O) = $45.06 \div 16 = 2.817 = .704 \times 4 = 4$		
\therefore Formula is Na_2SO_4 .		

Problem III.—Find the weight of a substance formed from a given weight of a known substance.

Solution.—1. Write down the equation representing the reaction. 2. Write the weights of the substances under the formula. 3. Calculate by simple proportion.

Example.—Find what weight of tri-manganese tetroxide will be formed on calcining one ton of manganese carbonate ; also the loss per cent., and hence the percentage increase of manganese.

Equation: $3 \text{MnCO}_3 + \text{O} = \text{Mn}_3\text{O}_4 + 3 \text{CO}_2$

Weights: 3 (55 + 12 + 48) parts yield (55 \times 3 + 16 \times 4) and lose 3 (12 + 16 \times 2) on heating.

Simplifying: 345 parts yield 229 parts and lose 116 parts on heating.

Proportionately: 2,240 lbs. form $229 \times 2,240 \div 345 = 1,493$ lbs. = 13 cwt.

Loss per 100 parts = $116 \times 100 \div 345 = 33.623$.

Percentage of manganese $229 \times 100 \div 345 = 66.377$.

The percentage of manganese increases from $165 \times 100 \div 345$ in the carbonate to $165 \times 100 \div 229$ in the oxide; *i.e.* from 47.826 to 72.052 on calcining.

Hence percentage increase of manganese = $229 \times 100 \div 345 = 66.377\%$. From this the factor for Mn_3O_4 from MnCO_3 is got, *viz.* .66 (approximately).

SOME USEFUL FACTORS.

<i>Given Unit Weight of</i>	<i>To find the Amount of Present.</i>	<i>Proportion.</i>	<i>Factor.</i>	<i>To find Amount of Obtainable.</i>	<i>Proportion.</i>	<i>Factor.</i>
FeCO_3	Fe	$56 \div 116 =$	.4828	FeO	$72 \div 116 =$	0.6207
FeS_2	Fe	$56 \div 120 =$	.4667	Fe_2O_3	$160 \div 240 =$	0.6667
Fe_3O_4	Fe	$168 \div 232 =$	.7241	FeO	$216 \div 232 =$	0.9310
Fe_2O_3	Fe	$112 \div 160 =$	.7000	FeO	$144 \div 160 =$	0.9000
FeO	Fe	$56 \div 72 =$	.7778	Fe_2O_3	$160 \div 144 =$	1.1111
CaCO_3	Ca	$40 \div 100 =$	.4000	CaO	$56 \div 100 =$	0.5600
CaS	Ca	$40 \div 72 =$	.5556	CaO	$56 \div 72 =$	0.7778
MnCO_3	Mn	$55 \div 115 =$	.4786	Mn_3O_4	$229 \div 345 =$	0.6638
MnO	Mn	$55 \div 71 =$	.7747	Mn_3O_4	$229 \div 213 =$	1.0751
MgCO_3	Mg	$24 \div 84 =$	.2857	MgO	$40 \div 84 =$	0.4762
P_2O_5	P	$62 \div 142 =$	.4366			
SO_3	S	$32 \div 80 =$	.4000	SO_2	$64 \div 80 =$	0.8000
SO_2	S	$32 \div 64 =$	.5000	SO_3	$80 \div 64 =$	1.2500

Although the fourth decimal place is indicated, only the third significant figure need be taken as an approximation.

TABLE OF THERMAL AND PHYSICAL CONSTANTS USEFUL IN CALCULATIONS ON COMBUSTION.

Calorific Power of Carbon Burning to Gas.	C.U.	Density of Gas.	Weight of one cub. ft. in lbs.	Weight of one litre in grammes.	Specific Heat.	Calorific Power of Gas, C.U.	Factors for Combustion of			Factors for Volume of Pro- ducts of Combus- tion from Unit Volume of Gas, Stem., CO ₂ .
							Unit Weight of Gas.	Unit Volume of Gas.	Unit Volume of Gas.	
							Oxygen.	Air.	Oxygen.	Air.
CO ₂	8,080	22	·1234	1·9712	·2169	...	...	...	...	...
CO	2,400	14	·0784	1·2544	·2450	2,400	·572	2·49	0·5	2·38
CH ₄	1,543	8	·0447	0·7168	·5929	12,000	4·00	17·4	2·0	9·52
C ₂ H ₄	663	14	·0784	1·2544	·4040	10,400	3·43	14·9	3·0	14·28
C ₂ H ₂	1,852	13	·0734	1·1648	(?)	11,500	2·86	12·4	2·5	11·9
H	...	1	·0056	0·0896	3·409	29,300	8	34·8	0·5	2·38
O	...	16	·0893	1·4336	·2175	C.U. = Centigrade Units.				
Steam (H ₂ O)		9	·0502	0·8064	·4805	C.U. $\times \frac{9}{5} = \text{B.Th.U. (British Thermal Units.)}$				
N	...	14	·0784	1·2544	·2438	Volume of a gas increases by $\frac{1}{273} = (.003663)$ of itself for each one degree centigrade (1°C) rise of temperature.				
Air	(N + O)	14·438	·0809	1·2936	·2375	Air contains				
						By Weight. By Volume.				
						N 77% 79%				
						O 23% 21%				

The calorific power of a fuel is the number of heat units evolved by the complete combustion of one pound (1 lb.) of it.

The heat unit is the amount of heat required to raise 1 lb. of water 1 degree (B.Th.U. 1 degree Fahrenheit).

The specific heat of a substance is the number of heat units required to raise the temperature of 1 lb. of it one degree.

The density of a gas is half its molecular weight.

USEFUL FACTORS IN CALCULATING BLAST FURNACE CHARGES BASED ON FORMING
MONOSILICATES $2 RO, SiO_2$.

<i>To find</i>	<i>Required to Combine with one part of</i>	<i>To Form Mono- silicate.</i>	<i>Proportion.</i>	<i>Factor.</i>	<i>Reciprocal, i.e. Factor for Silica for 1 Part of Base.</i>	<i>Lime Equivalent.</i>
Alumina	Silica	$2 Al_2O_3, 3 SiO_2$	$180 \div 204 =$	·8824	1·133	$\frac{56 \times 3}{102} = 1·6$
Lime	Silica	$2 CaO, SiO_2$	$60 \div 112 =$	·5358	1·866	$\frac{56}{56} = 1·000$
Magnesia	Silica	$2 MgO, SiO_2$	$60 \div 80 =$	·7500	1·333	$\frac{56}{40} = 1·400$
Manganous Oxide	Silica	$2 MnO, SiO_2$	$60 \div 142 =$	·4226	2·367	$\frac{56}{71} = 0·788$
Iron	Silica	$2 FeO, SiO_2$	$60 \div 112 =$	·5358	1·866	$\frac{56}{56} = 1·000$
Ferrous Oxide	Silica	$2 FeO, SiO_2$	$60 \div 144 =$	·4167	2·400	$\frac{56}{72} = 0·777$
Lime	Sulphur	Ca S	$56 \div 32 =$	1·75	...	...

One half of the manganese in the ore passes into the iron along with all the phosphorus.

The pig-iron formed is usually assumed to contain 92 % of metallic iron, with 2·5 % of silicon.

Practically all the sulphur in the ore passes into the slag as calcium sulphide (CaS)

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